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Providing Better Energy Efficiency for Russian Buildings by Greater Insulation

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DESCRIPTION

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Abstract

The purpose of this thesis work was to determine whether it possible to implement the Passive House technologies in Russian conditions on the example of remodeling of the external wall structure of the existing one-family house.

For this was made a model of one family house, situated in Saint-Petersburg region. In the calculations are used 2 different wall envelopes – wall type I and wall type II (before and after remodeling correspondingly). Wall type I is ordinary brickwork with inside insulation. Wall type II is a constructive, developed by Knauf company according to the Passive House regulations. It add 150mm insulation to the structure, decreasing total U-value.In order to determine the effectiveness of this implementation the investment project was simulated.

Original investment in the investment project is the estimated cost of remodeling. Inflow was the annual energy saving calculated for the 3 types of heating systems (DH, electricity and gas). Energy saving were provided by heat losses difference before and after renovation.

The payback time of the renovation varies from 18-27 years. This result is explained in this thesis work by a number of economic and technical reasons. Also in this thesis work were developed requirements allowing Passive House technologies to be implemented on the Russian construction market.

Subject headings, (keywords)

Building envelope, energy efficiency, passive house, heat losses

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CONTENTS

1 INTRODUCTION

Innovation are vital to many aspects of life and business, they open up new possibilities for things to which we are accustomed. This is largely true for the construction too. Enormous changes have occurred in the construction industry in the last century - for instance, in America in beginning of the century buildings began to grow into the third dimension. Implementation of steel structures technologies made possible the construction of skyscrapers. Currently, there is a new benchmark in the development of construction industry. This benchmark is minimization of energy consumption of residential buildings and environmental safety. Particular interest is the minimization of energy consumption, which leads to a decrease of heating costs, as well as reduction of carbon emissions during its production.

Residential houses in Europe consume about 40% of all energy. Of which 75% goes for heating and cooling 15% for electricity supply, particularly - lighting. In general, 30% of primary energy in Europe is used for heating and cooling of dwelling areas and 5% - for electricity /1/. The situation now is that in next 10 to 20 years, the price for energy resources can grow on 70%. Due to the fact that energy resources mostly come from other countries to Europe, as well as with growing complexity of their production and limited supply, such cost increasing is quite likely to happen.

Energy production intersects directly with the environmental issues. 94% of all carbon dioxide emissions falls on energy production and consumption. Rising carbon dioxide emissions and it’s associated climate changes, as well as dramatic reduction in the energy resources of the planet has led the European Union to adopt the document, known as the EU-Klimaschutzpaketes 20-20-20 /2/. In this package of EU documents were announced the following goals by 2020:

- Reduce carbon emissions by 20% (compared to the baseline in 1990);
- Reduce energy consumption by 20% (compared to the baseline in 1990);
- Increased share of renewable sources in the total primary energy consumption up to 20%

For Europeans the struggle for power savings began with the 1973 oil crisis. Then, because of the war in the Middle East on fuel prices increased by 4 times. Since then, oil and gas is only getting more expensive, and continuous improvement of industrial energy efficiency and communal services become common European ideology. Rapidly began to develop technologies of houses with zero energy consumption, passive houses, automated heating, began to apply renewable energy sources, etc. This situation has led to the fact that at July 8, 2010 entered into force the European Directive of energy efficiency of buildings - Energy Performance of Buildings Directive (EPBD)/3/.

The main goals and objectives of the EPBD are:

- Improving energy efficiency of buildings;
- Use of renewable energy sources.

The right to determine the minimum requirements (for example, the coefficient of thermal conductivity of designs for buildings) is still up to the EU member states. Until 31.12.2018 EU countries must ensure the following: all erected new buildings must generate as much energy as they consume. Resolution provides for the development of national programs and action plans to increase the number of "zero-energy houses" by all EU member states. In addition, it requires a clear definition of the share of "homes with zero energy consumption" in the total housing stock from 2015 to 2020. Especially active construction of "passive" houses is conducted in Germany, Denmark, Norway and Sweden, where the climatic conditions are comparable to central Russia. Totally in Europe in recent years built thousands of similar objects.

Another vital compound of the increasing of energy efficiency in this area is remodeling of the existing building, which decrease their energy consumptions. There are many different solutions how to improve the energy efficiency of buildings:

- Reducing heat losses through building envelope;
- Reducing thermal bridges;
- Improved sealing of the building;
- Improving efficiency of service systems;
- Improved monitoring and control of the heating system;
- Efficient use of internal heat flow in buildings;
- Preventing overheating of the building in the summer avoiding cooling;
- Implementation of renewable energy sources.

Russia also had preconditions for developing of low-energy consumption buildings. Soviet scientists under the authority of the professor Yuri Lapin began to develop systems for reducing energy consumption back in the 80th of the last century /4/. However, the idea did not find the application due to the cheap energy and a positive environment on the oil market. At that time were built a huge amount of building with a very low thermal insulation, not suitable for Russian the climatic conditions.

According to various estimates, the energy consumption for heating and ventilation in the total energy balance reaches 60-70%, of which about 40% is due to worn heating plants and 30% - slightly insulated building. Precisely apartment houses of bearing-wall construction, built in the 1960-1980’s became an issue of modern Russian housing and communal services/5/.

Now, due to the presidential decree of June 4, 2008. № 889 "Of some measures of improval of energy and environmental performance of the Russian economy" has begun implementation of measures, which improve the energy efficiency requirements for buildings with a goal to reduce energy consumption in 2020 by 40% compared to 2007. /6/. Such measures are not only necessary to reduce the use of energy for heating, but on the other hand under the Kyoto Protocol /7/ of 1999 contribute to the development of the energy business in Russia due to reduce of the number of energy resources for housing needs.

Now there is a review of the construction regulatory framework, due to recently enacted laws. At the same time, update of some regulations is long overdue. These documents include and SNIP 23-02-2003 "Thermal protection of buildings" /8/, which was created to replace SNIP II-3-79 * "Building Thermal Engineering"/9/. It is also necessary to improve the standard documentation for the designing of the building envelopes and heating systems. In adjustment of the existing regulatory framework and developing rules of their improval is engaged Professor NIISF RAASN VG Gagarin /10/ and doctoral candidate of SPbSTU A.S.Gorshkov /11/. Updating the building regulatory framework and bringing it to an analog with the existing European standards, the accuracy of the calculations will significantly increase and as a consequence energy efficiency of designed buildings.

1.1 THE PROBLEM OF RESEARCH. ASSUMPTIONS

The logical step for reducing the amount of thermal energy for heating purposes is increasing of thermal resistance of the building envelope. But implementation of new energy efficient technologies cannot only affect future buildings. It should also consider renovation of the existing ones. In USA, Canada and a lot of Europe countries exist special companies, which remodel old house according to all passive house standards.

The aim of this work is to analyze the possibility of using energy-efficient measures on example of additional internal insulation, made in accordance with the requirements for Passive houses for renovation of the existing one-family house in Russia. To answer this question was created simulation model, which will be described below.

Object of study is a cottage located in Saint-Petersburg. This cottage has two types of external wall envelopes, wall type I –before renovation and wall type II- after renovation. Wall type I is an ordinary brickwork with inside insulation. Wall type II is a constructive, developed by Knauf company, with 150mm thickness of insulation layer. For this object was calculated heat consumption, compensating heat loss by two methods, because of different types of heating system:

- method of mean monthly temperatures
- method of hourly temperature

The calculation of the thermal energy consumption was produced in accordance with the National Building Standards of Finland D3 «Energy efficiency of buildings and structures" /12/ and the National Building Standards of Finland D5 «The method of computing power and energy consumption for space heating" /13/. Then were selected three of the heating system:

1. District heating
2. Electricity (by electric convectors)
3. Gas boiler

For each type of heating system was calculated cost of energy carriers with the dimension Rub/kWh. After that estimated cost of renovation was calculated and the efficiency of the investment project, which is one-off investment in this project. Inflow in this case will serve a cost difference of thermal energy consumption between the two compared states of wall structures before and after renovation, multiplied by the cost of energy carriers. After that the investment project is calculated taking into account the discounting factor. Ultimate criterion is a conditional payback period.

Assumptions in creating of research model:

1. The calculation is not take into account the connection with the window construction
2. Averaging of the linear thermal bridge coefficient
3. In calculating using hourly temperature method assumes that the convectors have thermostats
4. In calculating of the payback period is not taken into account the risks of the investment project

2 PASSIVE HOUSE

In this chapter Passive House, its technologies and reality of their implementation in Russia will be discussed. In this thesis work was made an attempt to figure out if the Passive House technology and other energy saving technologies are nearest future of building in Russia and what are the milestones and risks of it.

2.1 PASSIVE HOUSE IN COMMON

The standard system of heating systems in Central Europe, as well as cottages in Russia – is central water heating with radiators, pipes and a central boiler that runs on liquid fuel or gas. Typically buildings of old dwelling fund have heat load about 100 W/m^2. This means that every square meter should have a light bulb of 100 watts to replace the heating system. The main idea of a passive house can be briefly explained as follows: building heat losses are reduced to such an extent that an individual heating system is not required. The following idea is simple: the development of brand new energy-efficient structures and materials are crucial for the development of the Passive house as a trend.

The definition say that "A Passive House it’s a building, for which thermal comfort (ISO 7730)/14/ can be achieved solely by postheating or postcooling of the fresh air mass, which is required to fulfill sufficient indoor air quality conditions (DIN 1946)/15/ - without a need for recirculated air"/16/. This is the description given by Dr. Wolfgang Feist – one of the inventors of this conception. That description means that Passive House is a concept, instead of standard. Following those regulations and using the ventilation as a tool for the space heating is the main idea, which defines Passive House and shows the difference to the low-energy house. But in order to simplify those regulations into some kind of short list this two main requirements (or Performance Characteristics) can be followed:

- Annual heat requirement not to be exceed 15 $kWh/m^2/year$
- Total annual primary energy consumption less than 120 $kWh/m^2/year$

Primary energy in the energy industry is called the energy that is available in the natural energy forms, or sources, such as coal, gas, wind, earth energy. Primary energy cannot be used directly by the final consumer, for this it must be converted into secondary energy (electricity, fuel, heat, supplied by district heating networks, etc.) /17/.

Also there are some additional requirements varying with the climate zone of the building's location:

- U-value for windows $\leq 0.8\ W/m^2/K$
- Ventilation system with efficiency of the heat recovery more than 75%
- Thermal bridge construction coefficient ≤ 0.01 W/mK
- Airtight building rate less than 0.6 ($n_{50} \leq 0.6$ / hour) ACH 50 Pa pressure, measured by blower-door test.

Basic principles are universal and based on application of the units that are already present in the building. Methods of reduction of heat losses are known, tried and tested:

- Improved insulation of standard building elements (roof, walls, floors);
- Reduction of thermal bridges due to the quality of work;
- Sealing the building envelope;
- The use of special windows for passive houses;
- Highly efficient heat recovery from exhaust air.

Implementation of these five points is enough to achieve the passive house standard. A passive house does not need a fundamentally new or different kind of building elements and equipment, sufficient improvements of conventional elements; however, it should be a significant improvement. The point is that all the details so carefully combined in order to get a functionally correct solution. This natural, logical approach proved to be viable and successful development /18/. Nevertheless, the accent in this work will be put mostly to the insulation factor and discussed further.

2.2 PASSIVE HOUSE WALL ENVELOPES

Integration of passive house technologies is impossible without perfect-developed external envelopes like external walls, ceilings and windows. In this thesis work only wall structures will be discussed more precisely. Wall structures in passive house concept have specific features and techniques, which will be observed in this chapter.

2.2.1 INSULATION FACTOR

Passive house envelope is determined by the complex of rules and techniques as well as the passive house concept itself. It is inaccurate and nearly impossible to describe any of these factors without mentioning the others because of their mutual connections.

One of them is highly efficient windows. However, good envelope thermal insulation, applied with conventional, standard windows, does not provide adequate comfort. Near the windows is usually the place for heat emitters and heat losses through such conventional windows is almost impossible to balance with increased insulation. Without ventilation system with high efficiency heat exchanger it does not make sense to do especially careful insulation with increased thermal capacity, as the ventilation losses will be immeasurably more that the benefit from the additional insulation.

Thermal insulation of the passive house envelope has a major influence on the consumption of thermal energy required for heating. This insulation must:

- have the highest quality;
- be packed tightly and without gaps around the entire building.

Reduction of the heat losses most simply this is achieved with designing of the exterior walls with minimum possible area. Such a design of the insulation is cost-effective: if the area of the outer envelope is small, cost of construction is significantly reduced. It can be achieved with simple designer decisions: e.g. construction of extensions instead of separate buildings, avoid complex forms the outer envelope of the building insulation, design more compact buildings. The more building envelope is compact, the less must be invested into the project in order to reduce heat losses. Complex structures must be avoided: they are rarely used and are particularly expensive. Thermal insulation should be designed so that the thermal insulation shell unit was very simple and ductile.

Basic principles of good insulation:

- It is necessary to develop closed thermal insulation shell, that covers the comfort zone. All rooms with temperatures in the winter above 15 °C should be inside the shell;
- The shell, which is interrupted only with the installation of windows, should have in every place high heat-insulating characteristics. Minimal thickness of the insulation anywhere in the insulating shell is 25 cm (Unit 040 thermal conductivity, or λ = 0,04 W / (m ° C)) /19/.

Over the last five years were developed a number of exterior walls structures, which are suitable for passive houses:

1. Insulation system for exterior walls (two-layer structure) with the thickness of the effective insulation more than 25 cm.

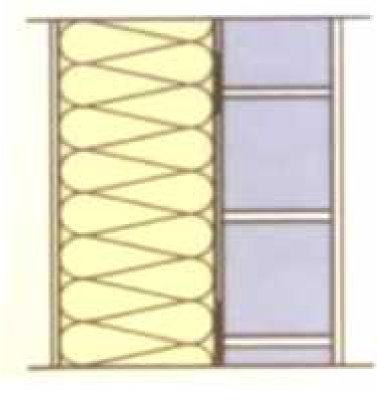

Fig.1 Two-layer structure

2. Fixed timbering from expanded polystyrene, which is filled with concrete at the construction site. It is easy to increase the outer layer of EPS timbering with a few centimeters to achieve the passive house standard.

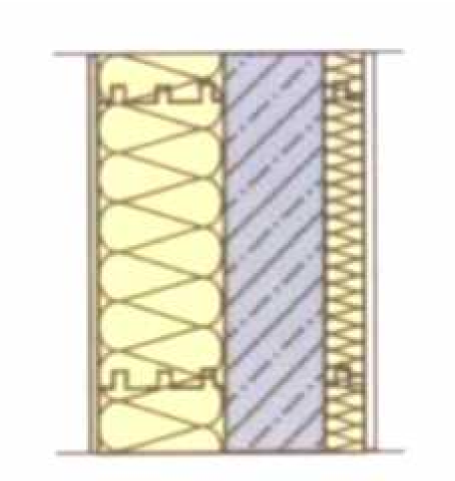

Fig.2 Concrete wall structure with fixed timbering

3. Elements of walls from wooden panels with lighted I-beams with more than 30 centimeters of insulation.

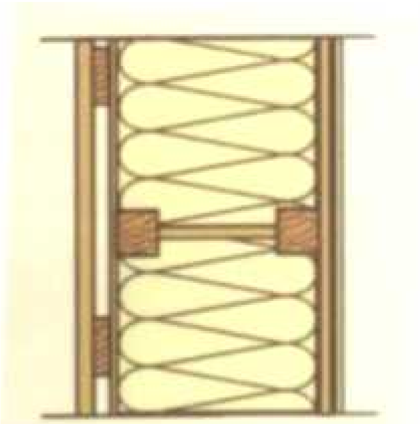

Fig.3 wall structure with lighted I-beams

4. Multilayer walling elements prefabricated and insulated with polyurethane foam.

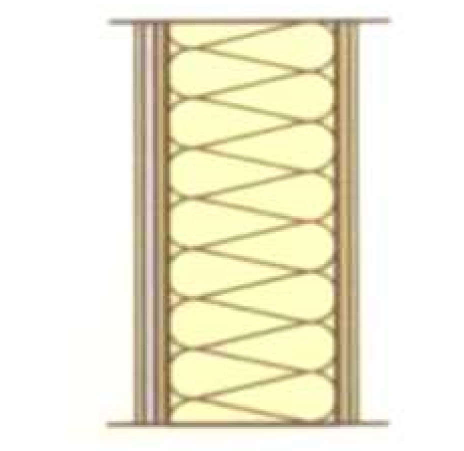

Fig.4 Prefabricated multilayer walling elements

5. Prefabricated elements of the lightweight concrete with integrated insulation

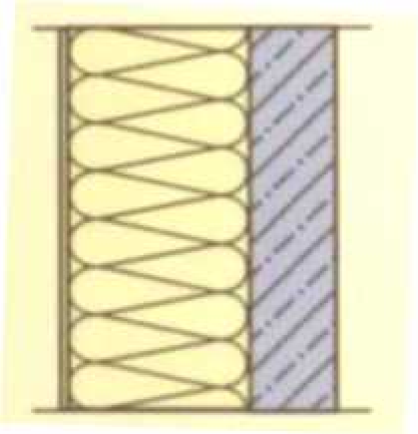

Fig.5 Prefabricated lightweight concrete wall structure

6. Block sheet piling made of boards walls with insulation, located on the outside.

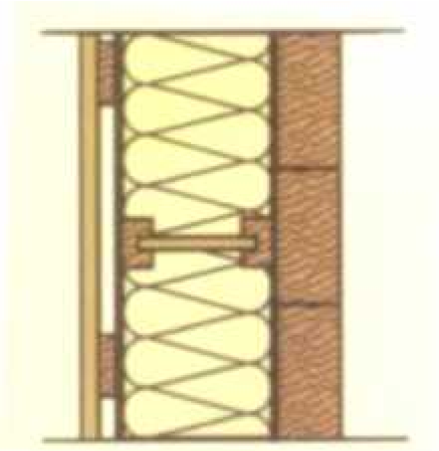

Fig.6 Outside insulated wall structure

7. Simple technology of natural material: building with bales of straw. This method is very popular in North America.

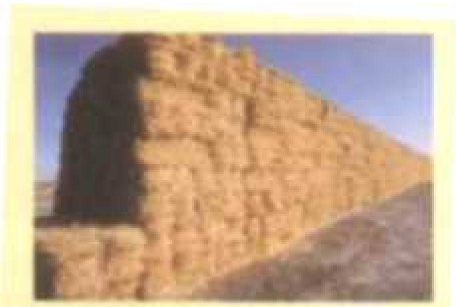

Fig.7 Straw insulated wall structure

8. High-tech version: vacuum insulation, which can be used successfully to achieve a low coefficient of heat transfer already at a thickness of 2.5 cm. Such technologies are not represented in Russia in meanwhile. I takes about 10-15 years in average to implement such innovations into Russian realms.

Fig.8 Highly-efficient vacuum insulation

In third chapter will be discussed different wall structured, which were used in this thesis work. One of the options is using Knauf wall construction and assumed to be Passive House wall structure. It corresponds to the first variant of the above design decisions, with the only difference that the insulating layer will be both inside and outside of the external wall.

2.2.2 THERMAL BRIDGES

Passive house envelope has two significant differs from other similar structures: construction without thermal bridges and highly airtight envelope. These two points are extremely important in the concept of the passive house along with highly efficient ventilation system and great insulation quality and quantity. These two points will be observed in this chapter with the exception of the passive house windows.

Very important point of Dr. W. Feist - "construction without thermal bridges", is successfully implemented in practice. In recent years in practice implemented techniques that minimize thermal bridges without compromising the functionality of the building.

There are four common rules which help to reduce heat losses arising from thermal bridges/19/:

1. **The rule of avoidance of thermal bridges**
   If possible, do not make holes in the insulating shell
2. **The rule of passage of insulation**
   If it is impossible to avoid holes in the insulating layer, it is necessary to maximize resistance to heat transfer in the layer of insulation in this place, for instance, use porous concrete or timber
3. **The rule of contiguity (for joints)**
   Location of insulation in the joints in the building elements must be with no blank spaces, meaning that the joint must be completely isolated
4. **The rule of geometry**
   If possible, choose the face with obtuse angles (> 90˚)

At designing is also used another rule - the whole outer shell (without exception) in a layer of insulation is encircled with a thick pencil layer (on the plan and section) on the scale, corresponding to the minimum required thickness of insulation - for passive houses it is 25 cm. This rule is represented by figure 9.

Fig.9 Fully closed, sealed envelope of Passive House in the city of Darmstadt, Kranihshtayn region.

Total specific heat losses are summed from heat losses across the surface of the outer shell and losses, taking into account the effect of thermal bridges. Design without thermal bridges is determined as follows: the effect caused by thermal bridges should be very small or zero. It is permissible not to include in the calculations the losses caused by thermal bridges, and thus greatly simplify the calculations. Heat losses are determined by the sum of (U • A) multiplied with temperature difference. Therefore, the envelope from the beginning should be classified as "without thermal bridges" when $\Psi a \leq 0{,}01$ W / mK. This condition applies to all structures such as joints (connections), the faces and the individual violation of the integrity of external insulating shell.

2.2.3 AIRTIGHT WALL ENVELOPE

External envelope of buildings must be airtight. This principle is established in the Construction Standards DIN 4108/20/. However, among some Russian designers there is a delusion that "walls need to breathe". Soviet scientists also wrote about this a long time ago (K.F. Fokin "Building Heat Engineering enclosing parts of buildings")./21/.But this is harmful for the thermal envelope, its durability and, moreover, leads to the removal of the heat. The idea of harmful effect of non-airtight envelopes has been written by Russian scientists back in 80s, but never got any support and was forgotten for decades. The air flow through the joints have a number of disadvantages. First of all, the air leakage through the joints in the external walls varies with the pressure of the wind and temperature fluctuations. In the most unsealed buildings in the windless, mild weather periods air exchange rate is insufficient. Ventilation, designed like this cannot provide required constant air flow. Secondly, if the air passes easily from the outside inside of the joint, due to the pressure of the wind inside the structure may get atmospheric precipitation. If the air flow passes from the inside out, then consequences will be catastrophic. Warm, moist air from the room is cooled, passing through the joint and, going out, could no longer contain the previous percent of humidity. Excess moisture condenses in the joint and structure gets saturated with the moisture /22/. Since the joint leakages do more harm than good, in "conventional" buildings envelope must be airtight, while in passive houses should be an excellent air-tightness of the envelope. At this case the necessary air exchange rate must be provided by the ventilation system. Ventilation through the joints in this case would disrupt the work of the ventilation system, and significantly increase the heat losses, as in such case the application of heat recovery is pointless.

Surface is already airtight, for example, the usual brick exterior wall, if it is covered with a solid interior plaster, performed without breaks. The internal plaster in such case shall be continuous from the finished floor to the bottom floor. It should also be plastered between the stair flights and the wall, even if "it is not seen". Wooden structures, such as hanging roof trusses, will be sealed, if a solid plastic film covers the entire surface of the insulation. Fabrics of the film must be carefully and securely glued, using double-sided adhesive sealing tape on the basis of the butyl rubber. Window glass connection and concrete floors envelope is also should be airtight. Tightness of buildings can easily be measured with the test pressure. Fan installed in an opening of the front door or window creates in the building a certain vacuum with normal value of the pressure difference is 50 Pa. Test pressure scheme is represented by figure 10.

Fig.10 Pressure test scheme

If the main structure is airtight, everything will depend primarily on the air-tightness of joints between building elements. The design should be guided by the following: airtight shell covers the entire heated volume and represents a completely closed surface. The internal volume of the building on the plan and section must be completely "circled" in pencil along the sealed surface without interruption. Air tightness can easily be achieved if:

- All items are projected in a simple design;
- Possible to perform large closed surfaces with the use of reliable and tested before basic structures;
- Guidelines for the joint installation are performed strictly;
- Through-piercing shells are minimal.

Very great difficulties cause breaks of the sealed envelope, so it makes sense to reduce the possibility of such punctures or limit them to a small, well-designed and made in good faith for this purpose. To solve the problem of technical holes in the structures, airtight boxes for electrical installation and special air-tight sleeves are used, for instance, to pass the pipe through the outer wall. Sealing is provided by plaster or plastic solution /8/.

3 CALCULATIONS

This chapter describes the basic calculations used in the study. For better understanding of the impact of doubling resistance to heat transfer while remodeling were made the calculation for two cases. First case describes the wall structure that was standing before remodeling. It was developed in accordance with SNIP "Thermal protection of buildings". The second case is describing new, remodeled structure with the wall structure which meets the Passive House standards. The difference between these two values is used in the economic analysis, to determine the payback period for further analysis.

3.1 RENOVATION OF THE EXISING WALL ENVELOPE

The object of study of the thesis is cottage located in St. Petersburg at Krasnogvardiysky district. Size of the area is 0.1 hectare. In the cottage resides a family of 4 persons.

Before remodeling the existing external wall structure is represented as one of the most common wall envelopes for one family houses in Russia. It is satisfying Russian normatives and standards and spread quite largely through the area. But major point in this thesis work is that after remodeling, the outer walls of the cottage meet the Passive House standards, e.g. thermal bridges absence and increased air tightness, which are harder to gain.

Layouts of the first and second floors are represented by figures 11 and 12:

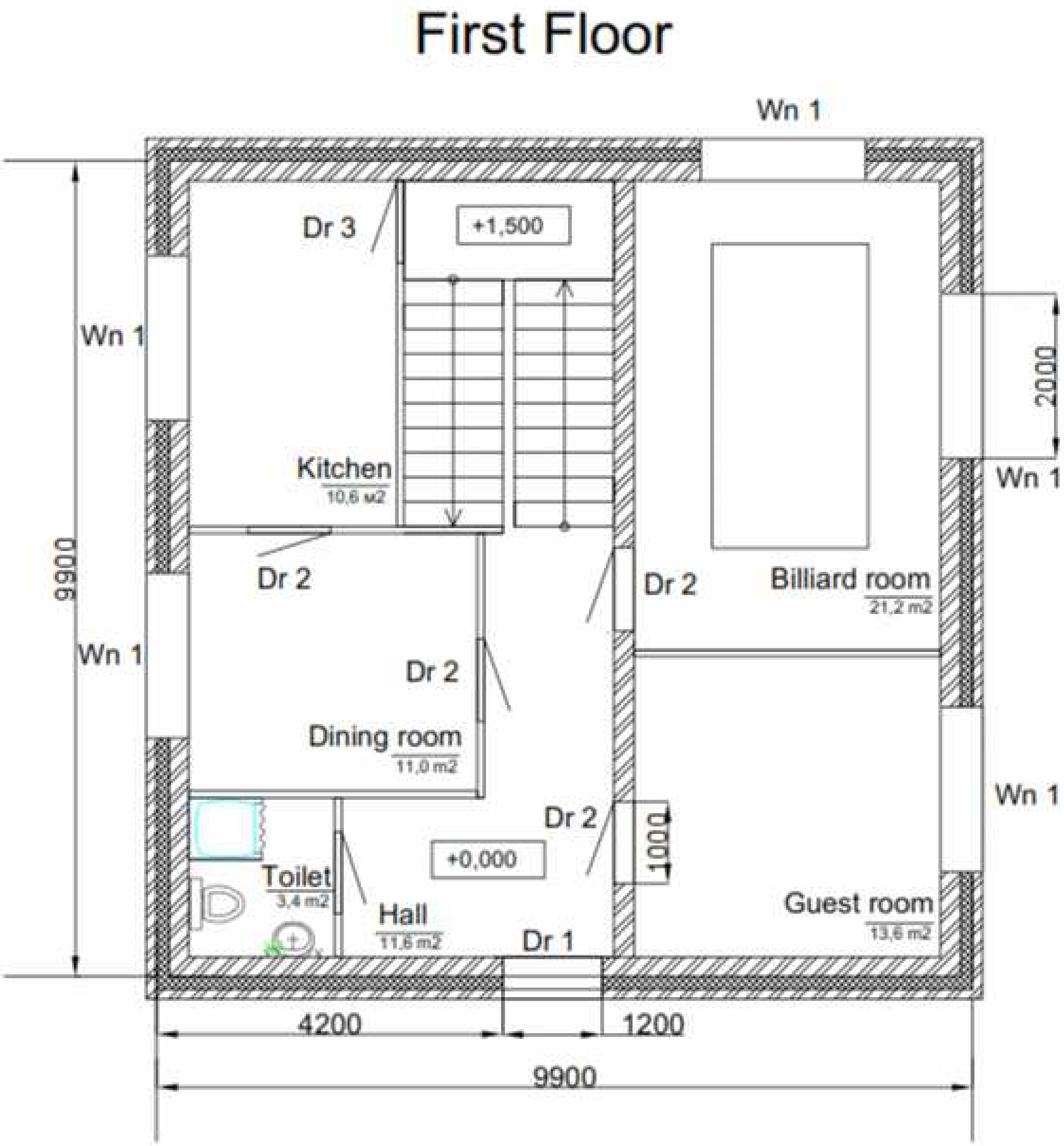

Fig.11 Layout of the first floor

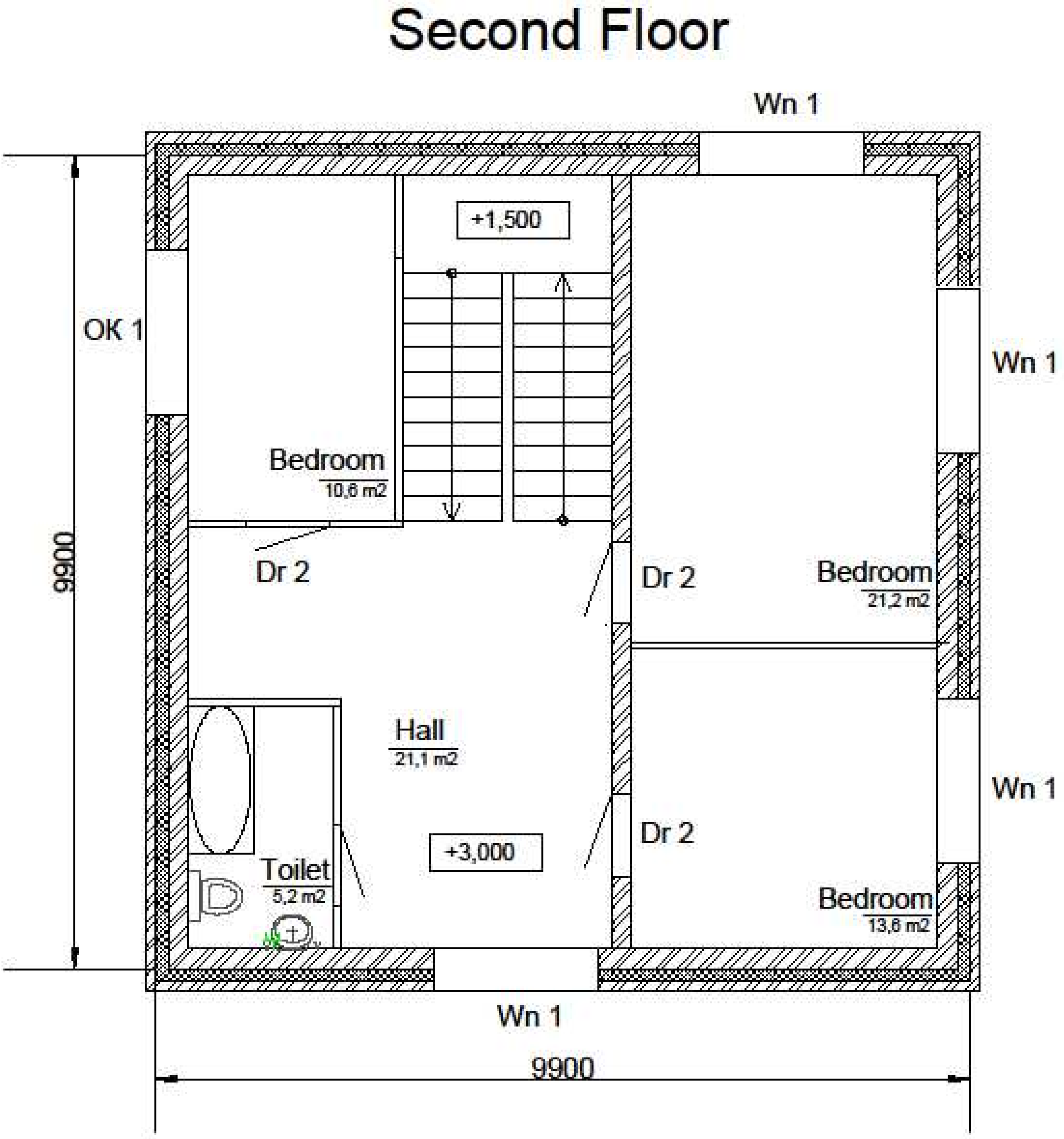

Fig.12 Layout of the second floor

List of areas and volumes of building envelope is presented below. Those numbers are used for the proper calculation of the amount of the insulation and other materials and works in the estimate. Case №1 represent wall type I and will be explained further, case №2 respectively represent wall type II.

Table 1. Area and volume explanation for different study cases

Thickness of insulation, mm	Brickwork		Insulation	Windows	Doors
Case №1	S, m^2	185	185	30	2,4
	V, m^3	72,4	22,4	10,8	0,84
Case №2	S, m^2	185	185	30	2,4
	V, m^3	72.4	22,4+27,8=50,2	11,7	0,94

3.1.1 WALL TYPE I

Insulation thickness of 120 mm corresponds to the wall type I is represented by figure 13. Justification of the choice of the thickness is contained in paragraph 3.2. This type of wall is called "well masonry". This construction is used for a long time and with time almost has not been amended. Depending on the thickness of the bearing wall, they differ in their solidity and sustainability. In this case, constructive looks like this – bearing wall 240 mm (two bricks), 120 mm insulation layer, 10 mm air gap and facing brick masonry 120 mm. In order to increase stability of well masonry layers are connected by vertical diaphragms, and at level of floor slabs and window openings are arranged with horizontal apertures. However this moment is one of the main minuses of the construction – those diaphragms are made by the staples of reinforcing steel with diameter 6-8 mm, which are thermal bridges for the envelope.

Obligatory condition of designing of well masonry is a ventilation gap between the insulation layer and the layer of the facing brick. Its minimum value is 10 mm, but in this thesis work it is 50 mm. Through the ventilation gap in the winter occurs an active drying of wall material. For the convection of air in the ventilation gap in the lower and the upper ranks of the masonry vertical joints must be cleared. Insulation boards are attached to the bearing wall on the mounting glue and additionally with expansion bolts. This is crucial moment for protection against the dew point, which will destroy the insulation layer in the winter period.

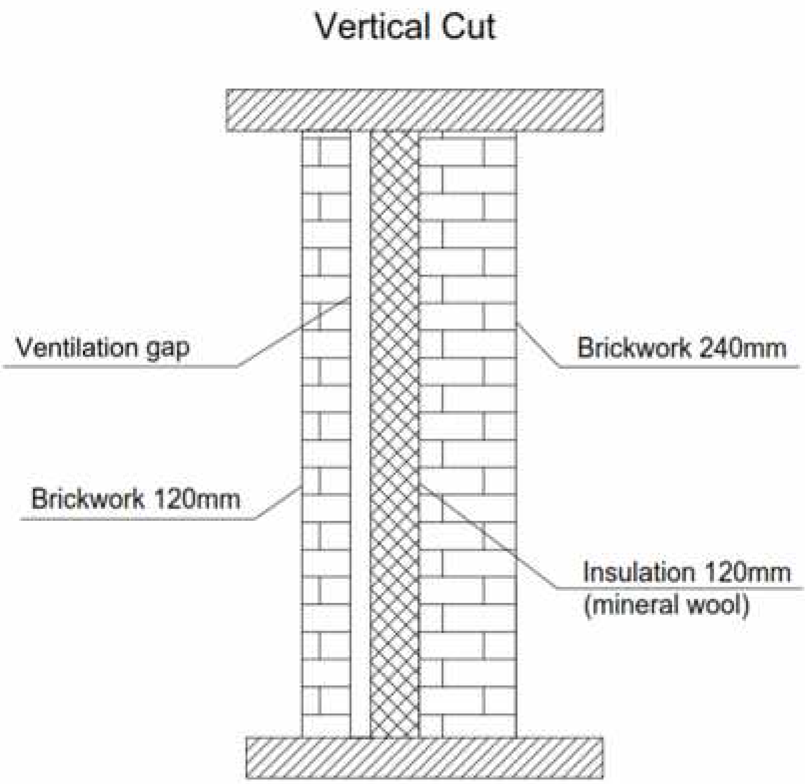

Fig.13 Wall type I vertical cut

3.1.2 WALL TYPE II

This type of wall is made in accordance with the construct of Knauf Company wall construction brand C626. Wall type II is a system of interior design with the use of thermal insulation. It corresponds to the Passive House standards and can be made with different thickness of insulation layer. In this thesis work this construction will a part of the remodeling of the one family house. It will be build inside the existing house in order to turn the external wall into the Passive House envelope. The type of mineral wool for the insulation is called Knauf Insulation 032, with a coefficient of thermal conductivity of 0,032 W/m•°C. Example of the corner butt joint, developed in accordance with the Passive House is shown on figure 14. Oblique hatching is representing existing external envelope – wall type I in this thesis.

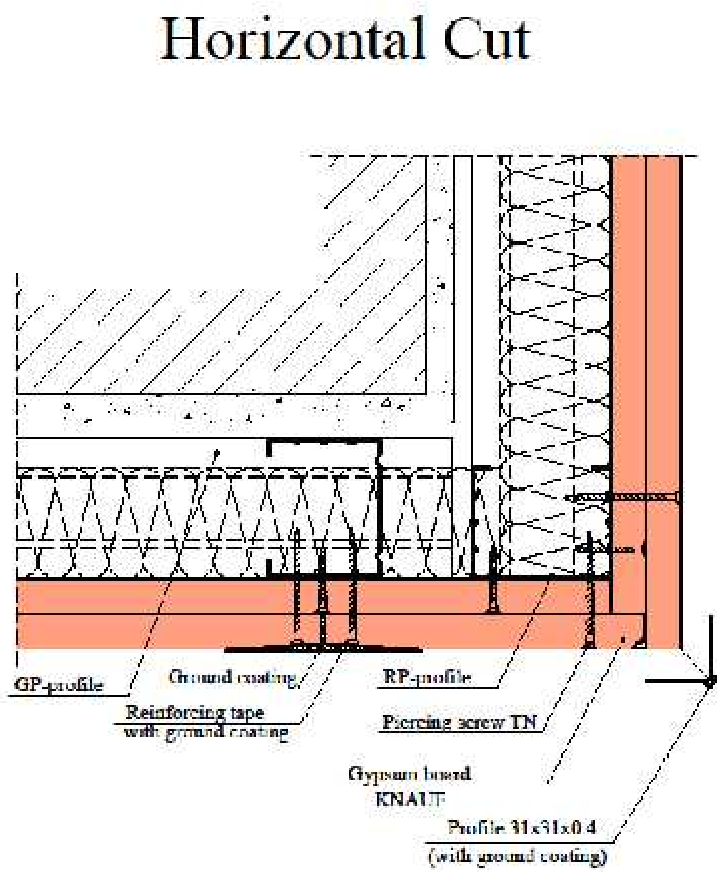

Fig.14 Wall type II horizontal cut

The fastening system is a metal profile rack-mount profile (RP) and guiding profile (GP). Guide profile is attached to the floor and ceiling dowels and has a width of 50 mm in this calculation. Inside of it is inserted vertically mineral wool of the same thickness, which is attached to standing every 600 mm rack mount profiles with dowels. It is vapor sealed, to avoid water condensate from the room with a special film. Additional thermal insulation is inserted between 50 mm insulation and bearing brick wall with 240 mm thickness. For money saving similar thermal insulation is applied, but with thickness of 100 mm if it is possible (e.g. 150mm = 50 + 100 mm). This reduces the estimated cost of construction. Finally on the inside RP is attached to the gypsum plasterboard Knauf, 12.5 mm in 2 rows, with dowels. All joints and cracks of wall construction are performed in accordance with the requirements of Knauf Company, which meets the requirements for the design of Passive Houses. The design scheme is shown on figure 15.

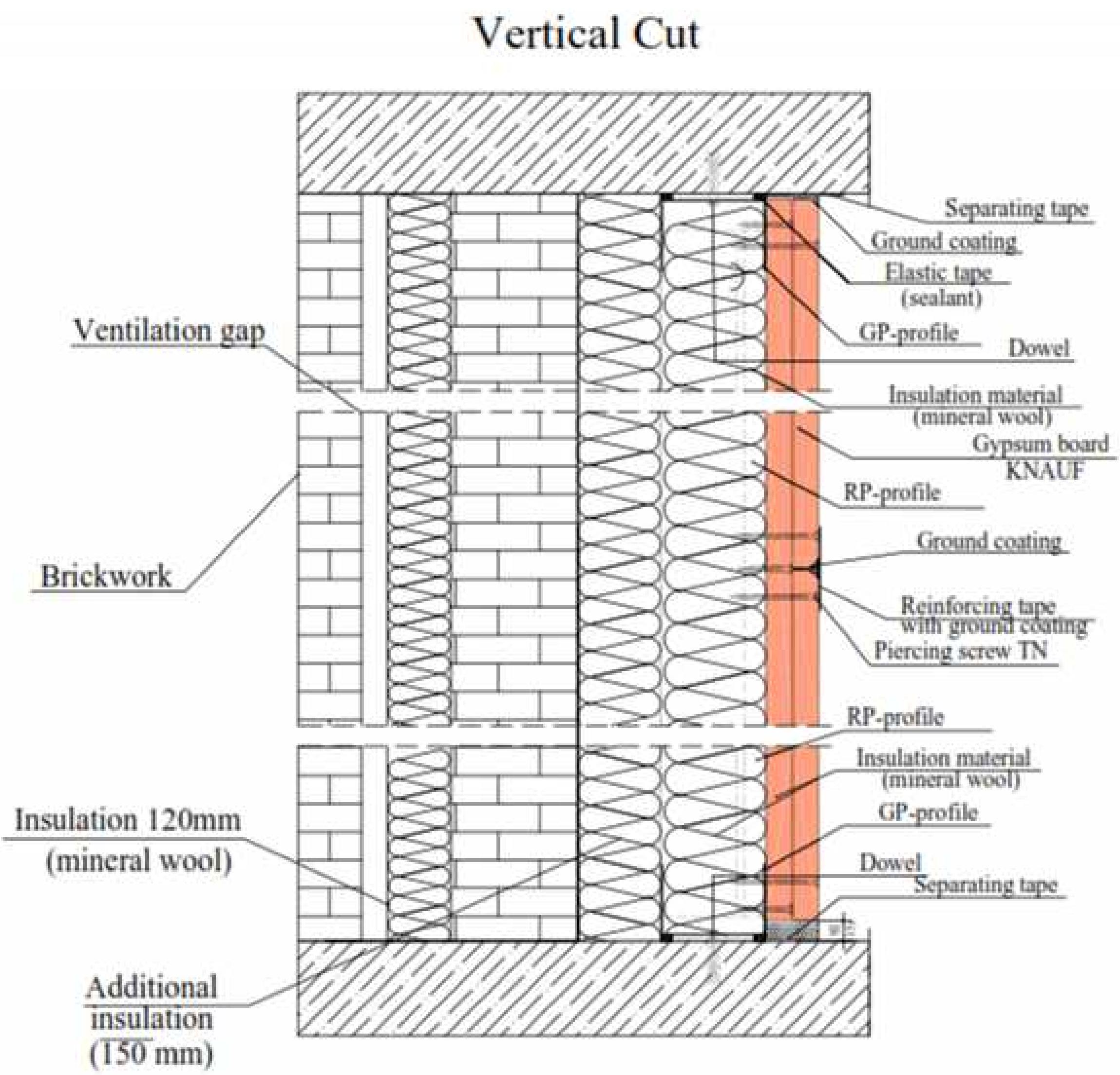

Fig.15 Wall type II vertical cut with different scale

3.2 CALCULATION OF U-VALUE

For the calculation must first be chosen the thickness of the insulation layer of the wall type I. To determine it uses data of SNIP "Thermal protection of buildings." Calculation is based on normalized parameters of thermal protection of the building "a", i.e. on normalized values of thermal resistance for individual building envelopes.

First of all, thermal resistance R_{req}, $m^2 \cdot °C/W$ is determined. R_{req} value depends on the D_d, by interpolation of the results from table 4. Heating degree-days of heating season - D_d, °C·days, is calculated by formula 1.

$$D_d = (t_{int} - t_{ht}) \cdot z_{ht} \quad (1)$$

Where

D_d	heating degree-days of heating season, °C·days
t_{int}	estimated average indoor air temperature of the building, °C
t_{ht}	average outdoor temperature, °C
z_{ht}	duration of the heating season, days.

Next, the calculation is made on the basis of methodological instructions on performance of the course work, "Calculation of the heat and humidity conditions building envelopes" by Barabanschikov J.G. /23/ For the St. Petersburg and Leningrad region on the basis of SNiP 23-01 /24/ and GOST 30494 /25/ the calculation is following:

$$D_d = (21-(-1{,}8))\cdot 220=5016$$

By interpolation find the value of R_{req} =3,14 $m^2\cdot°C/W$
Then select the correct thickness of insulation from the condition $R_{tot}>R_{req}$
Total resistance to heat transfer R_{tot} is calculated by formula 2.

$$R_{tot} = R_{si} + R_1 + R_2 + ... + R_n + R_{se} \quad (2)$$

Where

R_{tot}	total resistance to heat transfer, $m^2\cdot°C/W$
R_{si}	resistance to heat transfer at the inner surface, $m^2\cdot°C/W$
$R_1, R_2 ... R_n$	resistance to heat transfer of a homogeneous layer of a multilayered construction, $m^2\cdot°C/W$
R_{se}	resistance to heat transfer at the outer surface, $m^2\cdot°C/W$

Resistance to heat transfer of a homogeneous layer of structure is calculated according to formula 3.

$$R_i = \frac{\delta_i}{\lambda_i} \quad (3)$$

Where

R_i	resistance to heat transfer of a homogeneous layer of structure, $m^2\cdot°C/W$
δ_i	thickness of the i-layer of structure, m
λ_i	thermal conductivity of i-layer of structure, W/m·°C

Thus, obtain the inequality:

$$\frac{1}{23}+\frac{0{,}12}{0{,}81}+\frac{0{,}24}{0{,}81}+\frac{1}{8{,}7}+x>3{,}14 \text{ m}^2\cdot°\text{C/W}$$

Where 0,81 W/m·°C - thermal conductivity of brickwork. After transformation:

$$x > 2{,}53$$

When using a mineral wool Rockwool-Bats50 c thermal conductivity 0,047 W/m·°C, obtain the thickness of 120 mm. Thus:

$$\frac{1}{23}+\frac{0{,}12}{0{,}81}+\frac{0{,}24}{0{,}81}+\frac{1}{8{,}7}+\frac{0{,}12}{0{,}047}=3{,}16>3{,}14 \text{ m}^2\cdot°\text{C/W}$$

In the case of wall type II the construction already include thermal insulation of the wall type I, but with the additional thermal insulation provided by the materials of Knauf structure. Applied insulation have mark 032, which corresponds to 0.032 W/m·°C. In the construction of wall type II is using 2 layers of Knauf gypsum cardboard (12,5 mm) with coefficient of thermal conductivity 0.15 W/m·°C. The following is the calculation for structure which uses 150 mm of mineral wool:

$$3{,}16+\frac{0{,}15}{0{,}032}+\frac{0{,}025}{0{,}15}=7{,}85 \text{ m}^2\cdot°\text{C/W}$$

This value is approximately 2.5 times more than R_{req}. Heat transfer coefficient of the structure is calculated by the formula 4.

$$U=\frac{1}{R_{tot}} \tag{4}$$

Where

U heat transfer coefficient of structure (U-value), W/m^2·°C

All main data, calculated in chapter 3.1 is shown in the table 2.

Table 2 Main data of chapter 3.1

Constuction variant	Insulation thickness, mm	$R_{tot,}$ m^2·°C/W	U, W/m^2·°C	Volume of insulation, m^3
Wall type I	120	3,16	0,316	22,4
Wall type II	120+150=270	7,85	0,127	50,2

3.3 CALCULATION OF HEAT LOSSES

Building heat losses are calculated in accordance with the National Building Code of Finland D3 «Energy efficiency of buildings and structures". The calculation takes into account heat losses through the wall structures, thermal bridges and leakage of heated air through the wall structure. For the analysis only those heat losses will be taken into account, because only the difference between heat consumptions of the wall types I and II will be used in calculations. During the calculation only these three types of heat losses will change and the contribution of other types of heat losses will be the same and useless. Heat consumption that compensates heat losses through the walls is calculated using the formula 5.

$$Q_1 = U \cdot A \cdot (t_i - t_u) \cdot \Delta\tau \tag{5}$$

Where

Q_1	energy consumption, compensating heat losses through the walls, W·h
A	surface area of the building structure, m^2
(t_i-t_u)	difference between internal and external temperatures, °C
$\Delta\tau$	time period, h

Consumption of thermal energy due to leakage of heated air is calculated by the formula 6.

$$Q_2 = p \cdot c_p \cdot q_{v.l.a.} \cdot (t_i - t_u) \cdot \Delta\tau \tag{6}$$

Where

Q_2	energy consumption, compensating air leakage, W·h
p	air density, kg/m^3
c_p	specific heat capacity of air, 1 kJ/kg·°C
$q_{v.l.a.}$	air leakage flow, m^3/s

According to D3 air is leaking through the cracks of the wall structure, is calculated by the formula 7.

$$q_{v.l.a.} = \frac{q_{50}}{3600 \cdot x} \cdot A \tag{7}$$

Where

q_{50}	air leakage number of the building structure, $m^3/h \cdot m^2$
x	factor, depending on the number of the floors
3600	convert factor

According to D3 building structure air leakage number q_{50} is calculated by the formula 8:

$$q_{50.} = \frac{n_{50}}{A} \cdot V \tag{8}$$

Where

n_{50}	air leakage number of a bulding with a 50 Pa pressure difference, 1/h
V	volume of the building, m^3

For a two-story cottage x ratio = 24, in the case of the wall type I and ventilation with mechanical drive air exchange ratio n_{50}, according to SNiP 23-02-2003 ≤ 2 1/h. While for the wall structure II, performed according to the guidelines for the design of Passive Houses it is ≤ 0,6 1/h. Thus:

$$q_{50.,I} = \frac{2}{185} \cdot 564{,}5 = 6.1 \text{ m}^3/\text{h}\cdot\text{m}^2$$

$$q_{v.l.a.,I} = 0{,}014 \text{ m}^3/\text{s}$$

$$q_{50.,II} = \frac{0.6}{185} \cdot 564{,}5 = 1.83 \text{ m}^3/\text{h}\cdot\text{m}^2$$

$$q_{v.l.a.,II} = 0{,}004 \text{ m}^3/\text{s}$$

Heat consumption that compensates heat losses through the thermal bridges is calculated by formula 9.

$$Q_3 = L \cdot \Psi \cdot (t_i - t_u) \cdot \Delta\tau \tag{9}$$

Where

Q_3 energy consumption, compensating heat losses through thermal bridges, W·h

L thermal bridge length, m

Ψ additional thermal bridge conductance , W/m·°C

For the wall type I the Ψ value is averaged, taking into account angles, joints and other structural features of the wall structure and assumed to be 0.1 W/m·°C. The values for Ψ are taken from the Swedish Research Council Building normative "Tightness and insulation: Solutions for the Building Design" /26/. Ψ value for the wall type II, by parameters of Passive Houses ≤0,01 W/m·°C and equals this value. Thermal bridges, with length of the sections are presented in table 3.

Table 3 Thermal bridges description

Thermal bridge location	Thermal bridge length, m
Floor of the first storey	38,8
Floor of the second storey	38,8
Roof	38,8
Outer corner	24
Sum	140,4

The total consumption of thermal energy for the wall types I and II is following:

$$Q_{tot} = Q_1 + Q_2 + Q_3 \tag{10}$$

Where

Q_{tot} total energy consumption, compensating heat losses through the walls, W·h

Calculation of the total heat consumption will be made for the two cases. First one is monthly method, based on the average temperature for the region of St. Petersburg taken from SNiP 23-01-99. Second is based on the counted number of hours corresponding to a certain temperature of the external air (hourly temperature method). The data is taken from Table 2-5 of article from Engineering and Construction magazine SPBSTU "Feasibility study of ventilation systems with rotor heat recovery"./27/.

These two calculations are used because of the different sources of heating. If district heating (DH) used as a heating source, the heating season, according to SNIP "Thermal protection of buildings" will be 220 days. When the outdoor temperature for 5-days will be > 8 ° C, the heating season is over, so the first calculation (monthly) corresponds to the DH.

When using a gas or electricity as heating source, consumption depends on the room temperature, because it is assumed that the heater is equipped with the thermostat. Thus, the second calculation corresponds to these two heating systems.

Tables, calculated by the method of mean monthly temperatures are presented in Appendix 1 in tables 1-2. Tables, calculated by hourly temperature method are presented in Appendix 2 in tables 1-2. The results of calculations using the average monthly temperature method are given in table 4.

Table 4. Data calculated by monthly method

Wall type	Insulation thickness, mm	R_{tot}, $m^2 \cdot °C/w$	U, $W/m^2 \cdot °C$	Q_1, MWh	Q_2, MWh	Q_3, MWh	Q_{tot}, MWh
I	120	3,16	0,316	7,10	2,04	1,71	10,55
II	120+150	7,85	0,127	2,85	0,58	0,17	3,58

Data from table 4 presents as a figure 16.

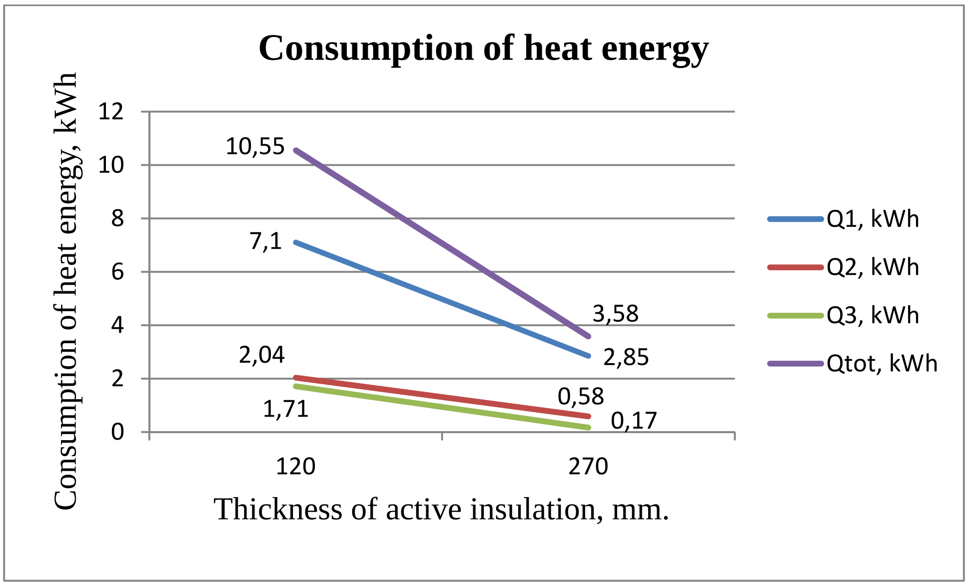

Fig.16. Consumption of heat energy, monthly method

The results of the calculation method of hourly temperature method are shown in table 5.

Table 5. Data calculated by hourly temperature method

Construction variant	Insulation thickness, mm	R_{tot}, $m^2 \cdot °C/w$	U, $W/m^2 \cdot °C$	Q_1, MWh	Q_2, MWh	Q_3, MWh	Q_{tot}, MWh
I	120	3,16	0,316	8,36	2,40	2,01	12,76
II	120+150	7,85	0,127	3,36	0,69	0,20	4,25

Data in table 5 presents as figure 17.

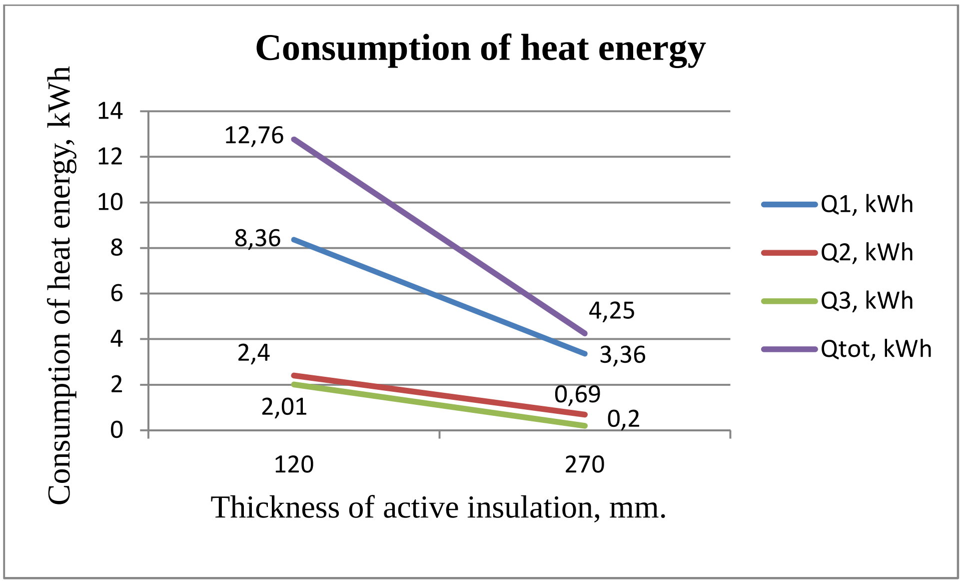

Fig.17. Consumption of heat energy, hourly temperature method

4 CHOOCHING DIFFERENT KINDS OF THE HEAT SOURCE

In this chapter will be discussed various types of heating systems. After that the most suitable type based on conditional payback period will be selected after the analysis of those three different options: district heating, electricity using electric convectors and gas boiler. Three different heating sources will be analyzed using AHP method to determine the most efficient way of heating. AHP method explanation is given in paragraph 4.4.

4.1 DISTRICT HEATING

Compared for example with electric heating, district heating system is fairly resource intensive. The system consists of: water heaters, pipes, directly heating devices, expansion vessel, shutoff and control valves. Pipeline hot water enters the heater tank, and after cooling back into the heating module. But despite technical and material complexity this heating system is long established itself in Russia.

Advantages and disadvantages of water heating system. Compared to other heating sources (HS), water systems have the following advantages:

- Low noise level
- Good uniformity of heat distribution, using "warm floor" system
- Relatively low operational cost
- Easy maintenance
- Ability to adjust the parameters of the system

Disadvantages are:

- High inertia - slow heating and cooling
- Significant hydrostatic pressure
- Significant capital expenditure
- Inability to regulate heat supply, especially if the system lacks of counters

The tariff for the connection of the cottage to St. Petersburg Heating Network range from 2-6 million rubles per one Gcal /28/, playing a significant role in the choice of heating system. It is also necessary to take into account the efficiency factor of the selected heating system. This ratio is shown in Table 6.6. D5 National Building Code of Finland ¦ =0,94. To price energy carrier formula 10 is used.

$$a_o = \frac{a}{¦} \tag{10}$$

Where

a_o	total cost of energy carrier, rub./MWh
a	cost of energy carrier, rub./MWh
¦	efficiency of the heating system

Price for central heating according to the Committee of Tariffs is given in Gcal. Gcal unit must be translated into MWh. Determine relationship:

1 Gcal =10^9 cal=4,1868x10^9 J
1 MWh =3,6x10^9 J
1 Gcal =1,163 MWh

According to the Committee of Tariffs of St-Petersburg price for 1 Gcal for the period from 01.07.2012 to 31.12.2012 for the consumer is 1175 rubles, including VAT/29/. Accordingly, obtain:

$$a_o = \frac{1175}{0,94 \cdot 1,163} = 1075 rub./MWh$$

According to the statistics of price growth for 2012 by the Committee of Tariff /30/, as well as the report of the Federal Tariff Service of increasing value natural monopoly services, the average price increase will be about 11%. The magnification factor of energy cost is given by formula 11.

$$\sim = (1 + \sim_0) \tag{11}$$

Where

$\sim$ coefficient of increasing of the energy cost
$\sim_0$ average annual increase of prices

For this heating system coefficient $\sim$ =1,11. These data are used into following 5.2 paragraph.

4.2 ELECTRICITY

The heating system model used for the calculations does not use an electric boiler and connects directly to the electric convectors. Electric convectors today are one of the most popular devices in the electric heating system of a one family house. Convectors popularity is due primarily of easy installation and maintenance, as well as a high degree of heat transfer. The principle of operation of electric convector is space heating by natural heat transfer. Convector heat cold air, which passes through the heating element and evenly moves through space, cools, sinks and reheats. Heat transfer, so that is 90-95% of the generated power, the remaining 5-10% of the heat is transferred through radiation.

Advantages and disadvantages of water heating system. Compared to other HS, electric convectors have the following advantages:

- High rate of convective heat exchange (90-95%);
- Rapid heating of the room;
- Relatively low operational cost;
- The ability to automatically control space heating;

- Good resistance to corrosion;
- Simple connection and minimum investment.

Disadvantages of using electric convectors:

- Unsustainable use for large rooms;
- Too dry air, which may be inappropriate for some rooms in the house;
- In most cases energy allocated for cottage is not enough for heating and other needs simultaneously;

According to the Committee of Tariff price for electricity connection is 6000 rubles, provided that the wires should be pulled less than 300 m. For the period from 01.07.2012 to 31.12.2012, the electricity tariff is:

- Day rate – 2,98 rub./kWh
- Night rate – 1,81 rub./kWh

On the assumption that the heaters will work around the clock, using two-part tariff for the electricity price will be the arithmetic mean of the prices of the above rates and will be 2.4 rub. /KWh. According to Table 6.6 from D5 National Building Code of Finland ¦ =0,99

Thus:

$$a_o = \frac{2400}{0,99} = 2424 rub./MWh$$

According to the statistics of price growth for 2012 provided by the Committee of tariffs, as well as the report of the Federal Tariff Service of increasing value of natural monopolies, the average annual price increase will be about 6%. For this heating system coefficient ~ =1,06. These data are used into following 5.2 paragraph.

4.3 GAS BOILER

The cheapest fuel in Russia - gas, and assuming that the land lot is connected to the gas line, then, in most cases, the installation of the gas boiler is the best option for investment and energy paying. When burning gas allocates the highest amount of heat compared to other fuels, at the same time emissions of environmentally harmful substances are significantly lower.

Advantages and disadvantages of water heating system. Compared to other HS, gas boiler have the following advantages:

- Efficiency. Cheap fuel at high efficiency;
- No need to store fuel;
- Long service life (50 years);
- Environmentally friendly;

Disadvantages of using gas boiler:

- When connecting the gas line require approval of project documentation from Gazgortehnadzor;
- Seasonal pressure surges in the pipeline could disconnect the heating system or damage the equipment;
- Risk of gas leakage;

Cost of installation of gas heating system varies on the type of gas boiler. The most expensive and effective (in terms of efficiency of the plant) is a condensing boiler. The estimated cost of such connection of the heating system, including work on installation and commissioning is about 1 million rubles. According to the Committee of Tariffs of St. Petersburg price for 1 m3 of natural gas for the period from 01.07.2012 to 31.12.2012 for the consumer is 4375.07 rubles including VAT /31/. According to the Table 6.6 from D5 National Building Code of Finland ¦ =0,81. One m^3 of gas fuel under normal conditions contains 10 kWh based on the estimated average calculations /32/. Thus:

$$a_o = \frac{437,5}{0,81} = 540,1 rub./MWh$$

According to the statistics of price growth for 2012 provided by the Committee of tariffs, as well as the report of the Federal Tariff Service of increasing value of natural monopolies, the average annual price increase will be about 15%. For this heating system coefficient ~ =1,15. These data are used into following 5.2 paragraph.

4.4 AHP METHOD

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was introduced by Thomas Saaty in 1977 and 1994. The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain. The AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, subcriteria, and alternatives. The pertinent data are derived by using a set of pairwise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, then it provides a mechanism for improving consistency /33/.

AHP method has its own mathematical model and it will not be discussed in this thesis. The procedure for using the AHP can be summarized as:

1. Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives.
2. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements. For instance, when comparing different heating sources, preferring some factors above another.

3. Synthesize these judgments to yield a set of overall priorities for the hierarchy. This would combine judgments about factors for 3 different options of heating into overall priorities for each factor.
4. Check the consistency of the judgments.
5. Come to a final decision based on the results of this process./34/

First of all for this calculation exist several initial data. The main one is said that this remodeling occurs in Russian Federation, meaning that all bureaucracy normative of connection must be accomplished. After that there are 3 different options of choices (a_1- gas, a_2-electricity and a_3- DH). For each of them are taken into account 5 factors, which allow to determine the best solution according to the initial data. In this calculation the main initial data is that the cottage is not connected to any heating source. Those factors are – environmentally friendly, carrier cost, connection, adjustment, maintenance. Those relationships are shown at figure 18.

After the criteria were determined they need to be pairwise compared by each other. For this purpose initial matrix for the criterion pairwise comparisons was made (Attachment 4, table 1). In AHP method comparison is figured mathematically by putting the coefficient inside the matrix. It is symmetric, with the diagonal, filled with 1, meaning comparison between the same criteria. If the criterion is more important than the other one, the coefficient is placed in the string of the most important criterion.

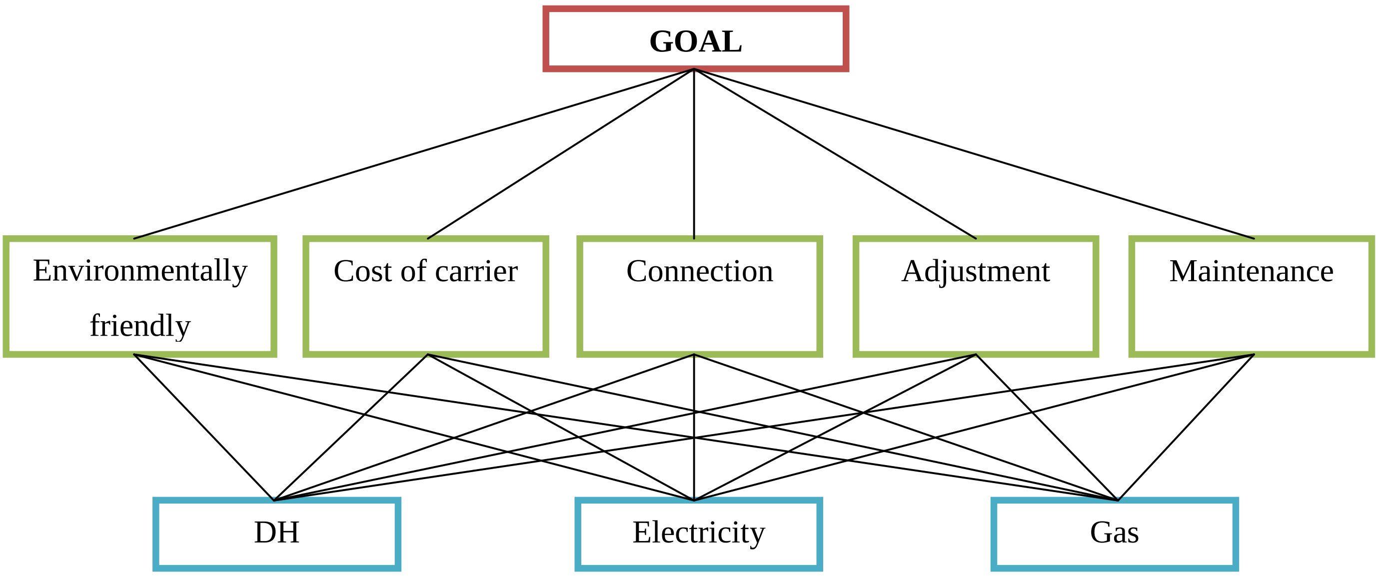

Fig.18. AHP method scheme

Those criteria relations can be found according to the table 1 (the fundamental scale of absolute numbers) from Thomas Saaty article in Int. J. Services Sciences, which is shown below/34/. Additional note – the comparative numbers cannot exceed 9. After mathematical evaluations euginevector for all criteria is found (matrix solution).

Table 1 The fundamental scale of absolute numbers

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

After that the same matrix were made for the options pairwise comparison. Those matrixes are calculated in Attachment 4, table 2. According to the matrix solutions all euginevectors must be equal 1 in sum. In Attachment 4, table 3 all euginevectors from previous 2 tables are given. Their multiplication, which is simultaneously the final result of the method, is given in the table 6.

Justification of the importance is quite a personal issue. It cannot be evaluated objectively, so it depends only on the experience of the compiler. Criteria explanations are given below.

1. Environmentally friendly – in Russia this idea is not very popular for several reasons, meaning that this criterion have the lowest weight among the others.
2. Cost of carrier – the second criterion of impotency. Obviously that the lowest cost of the carrier obtain the highest number.
3. Connection – the most important criterion, because of the initial data to the model. It consists of the price for the connection of the system and also the complexity of connection legalization.
4. Adjustment – it covers the heating season operating time, adjustment of the system itself and its efficiency.
5. Maintenance – it covers system's service life, complexity and maintenance price.

Table 6. Results of AHP method

Alternatives	Total weight for all criteria
a_1 - Gas	0,365883413
a_2 - Electicity	0,445681404
a_3 - DH	0,188435183
Sum	1

The most suitable option is electrical heating. Explanation of this result will be given in the Conclusion chapter.

AHP, like all methods of analyzing and modeling have some disadvantages. The biggest one is the process of importance coefficients evaluation. This is all the time very subjective decision, relying on the compiler professional judgment. But with this quite significant minus it still the most common and effective mathematical decision making model.

5 MARKET RESEARCH

This chapter will be made economic calculation and analysis of efficiency of the project, in terms of investment. Initially will be provided estimates for each of the designs. Then, based on data of reduction of energy consumption and the price of energy sources will be analyzed terms of payback period in each case.

5.1 VALUATION

The calculation of the estimated cost is made by the program Smeta Wizard, using the index of change of the estimated cost for August 2012 /35/. For more accurate calculations were used real prices on Knauf Company materials, taken from the pricelist of the Trading House "Petrovich" /36/, which is the official dealer of Knauf in Russia. They are calculated on a separate line - total unaccounted material. The calculation of the estimated cost for each type of wall construction is provided in Appendix 3 in the form of local estimate № 1.

5.2 INVESTMENT PROJECT EFFICIENCY EVALUATION

To evaluate the effectiveness of the investment project is usually used four indicators: the net present value (NPV), internal rate of return (IRR), payback period (T_{pb}), and sometimes the level of financial return (LFR). T_{pb} is a payback period and determined by the year in which the value of NPV is positive. To get the result must be determined the payback time, NPV value, as well as the profitability index I. Internal rate of return and the level of financial return will not be calculated. IRR is not calculated due to the fact that it is a one-time investment in the project in the first year, reference year of construction of the cottage, reversion is not considered because after lifetime object will remain in the ownership of the developer. Thus, the investments will not be discounted at all and will be equal to the difference between estimated costs of the different types of wall construction.

The basis for the calculation of the payback period was the application G2 of SP 21-101-2004 /37/. It has been modified to put in the research objectives and methods of calculation.The discount factor is calculated by formula 11.

$$\eta = \frac{1}{(1+r)^t} \tag{11}$$

Where

η	discount factor
r	discount rate
t	year of the investment project

In the calculation the discount rate will be equal to the index of official inflation in Russia. According to the IMF, it will be 6.5%, a similar rate is expected and for 2013 (on the basis of the report the head of the IMF mission in Russia Antonio Spilimbergo) /38/.

Investment is calculated by formula 12.

$$K_t = K_{est.} \tag{12}$$

Where

K_t	investment, rub.
$K_{est.}$	estimated cost of the remodeling, rub.

For the calculation of the cash flow by years it has been hypothesized that energy costs should increase every year. Cash flow by years is calculated by formula 13.

$$R_t = \Delta_Q \cdot a_0 \cdot \sim \tag{13}$$

Where

R_t	cash flow by years, rub.
Δ_Q	difference is the heat consumption of compared wall construction,

MWh

Discounted cash flow by years is calculated by formula 14.

$$R_{t\eta} = R_{t.} \cdot ¦ \tag{14}$$

Where

$R_{t\eta}$	discounted cash flow by years, rub.

A discounted cash flow by years on cumulative total is calculated by formula 15.

$$R^{t}_{t\eta} = \sum R_{tn}. \tag{15}$$

Where

$R^{t}_{t\eta}$ discounted cashflow by years on cumulative total, rub.

NPV is calculated by formula 16.

$$NPV = \sum (Kt + R^{t}_{t\eta}) \tag{16}$$

Where

NPV net present value, rub.

Profitability index is calculated by the formula 17. It indicates the quality of the investment. If this value is more than 1, it means that the project started to make income.

$$I = \frac{NPV}{Kt} \tag{17}$$

Where

I profitability index

For the district heating system calculations were made in the table form. The calculations are shown in Appendix 5 in Table 1. For electrical heating system calculations were made in the table form. The calculations are shown in Appendix 5 in Table 2. For the gas boiler heating system calculations were made in the table form. The calculations are shown in Appendix 5 in Tables 3.

The results of calculation of the relative payback period by comparing the wall type I and wall type II, with additional 150 mm insulation layer and district heating system are shown in figure 19.

In this case, T_{pb}=27 years, NPV value this year=7493,00 rub., I =1,034>1.

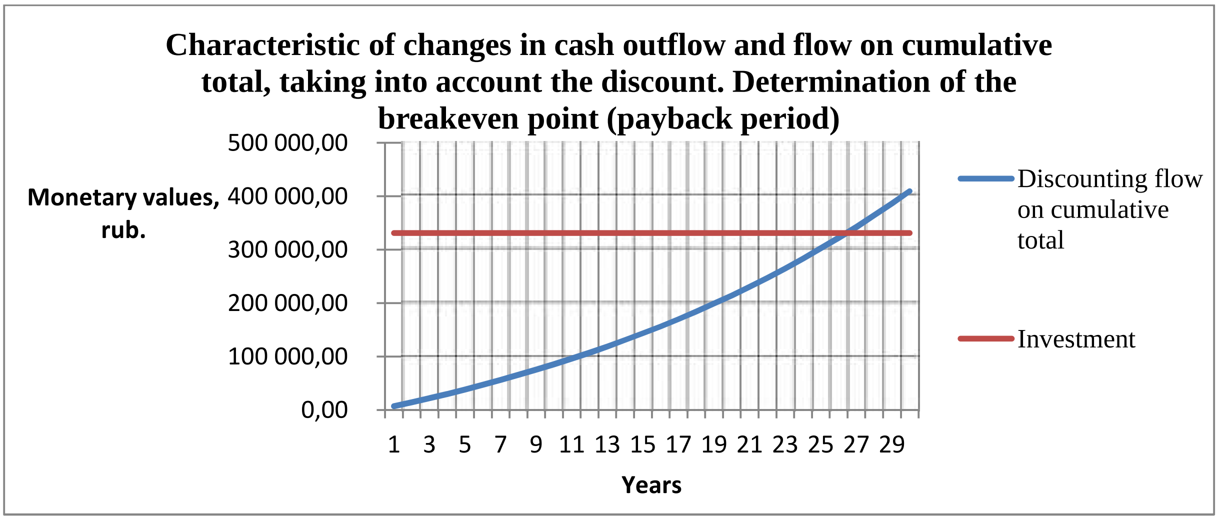

Fig.19. Payback time using DH as a heating source

The results of calculation of the relative payback period by comparing the wall type I and wall type II, with additional 150 mm insulation layer and electric heating system are shown in figure 20.

In this case, T_{pb} =18 years, NPV value this year =20628,20 rub., I =1,011>1

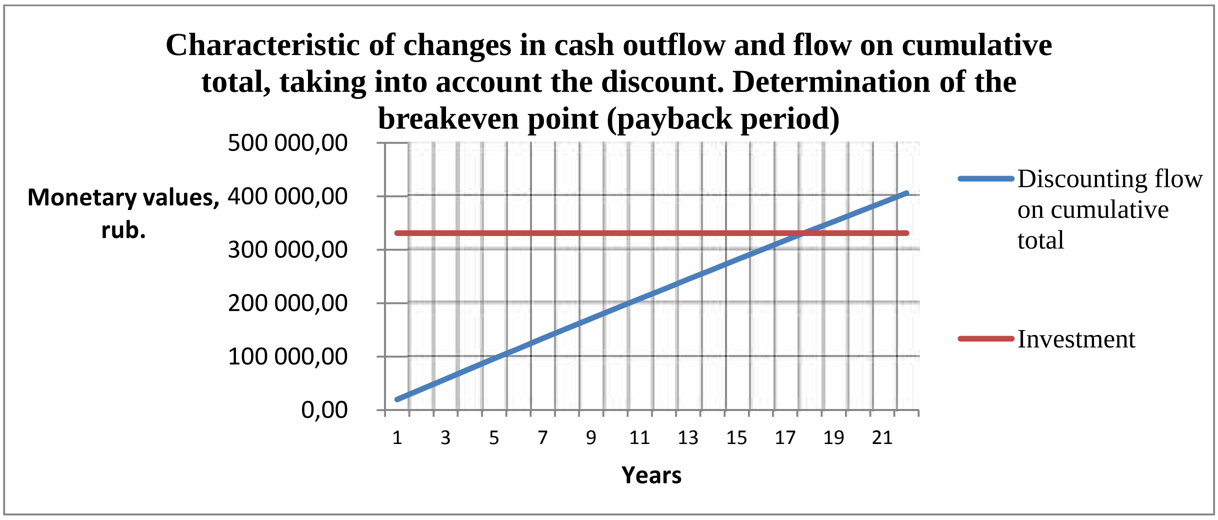

Fig.20. Payback time using electricity as a heating source

The results of calculation of the relative payback period by comparing the wall type I and wall type II, with additional 150 mm insulation layer and gas boiler heating system are shown in figure 21.

In this case, T_{pb} =26 years, NPV value this year =4596,30 rub., I =1,039>1

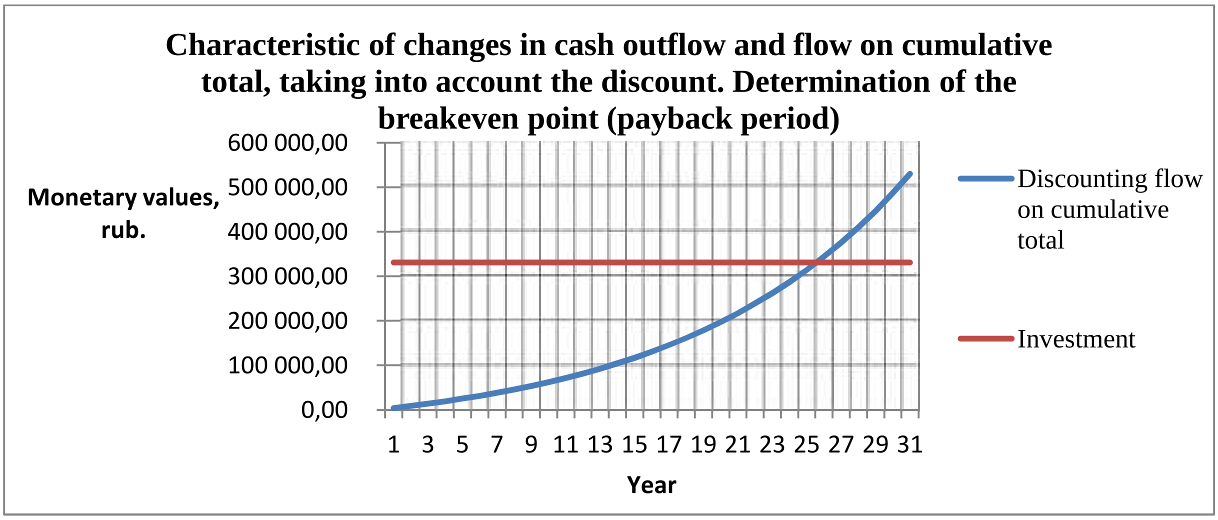

Fig.21. Payback time using gas boiler as a heating source

5.3 ANALYSIS OF THE RESULTS

The results of AHP method give the answer to the question – what is the best heating source under the given conditions. Mathematical model choose electricity as the best option of three. From one hand it has the most expensive carrier cost, but it was chosen according to another criteria – the connection. It is the highest criteria of all given, because of the condition that the cottage is not connected to any system yet. It will not only take incomparably more resources to connect one family house to the central (or not central) gas system or DH, but a huge amount of time too. Legalization and bureaucracy of this process can take half a year or even more. That is the main reason why it was chosen.

For simplification and further analyze data from figures 19-21 are represented in the table form. Calculation results for all heating systems are represented at Table 7.

Table 7. Analyze of market research

Insulation thickness, mm	Δ_Q , MWh	$\Delta_{est.}$, rub.	Inflow in the first year, rub.	~ ,%	I	Payback period, years
DH	6,97	331 229,00	7492,80	11	1,034	27
Electricity	8,51	331 229,00	20628,20	6	1,011	18
Gas	8,51	331 229,00	4596,30	15	1,039	26

The results of the payback period, depending on the thickness of the insulation layer are summarized in figure 22.

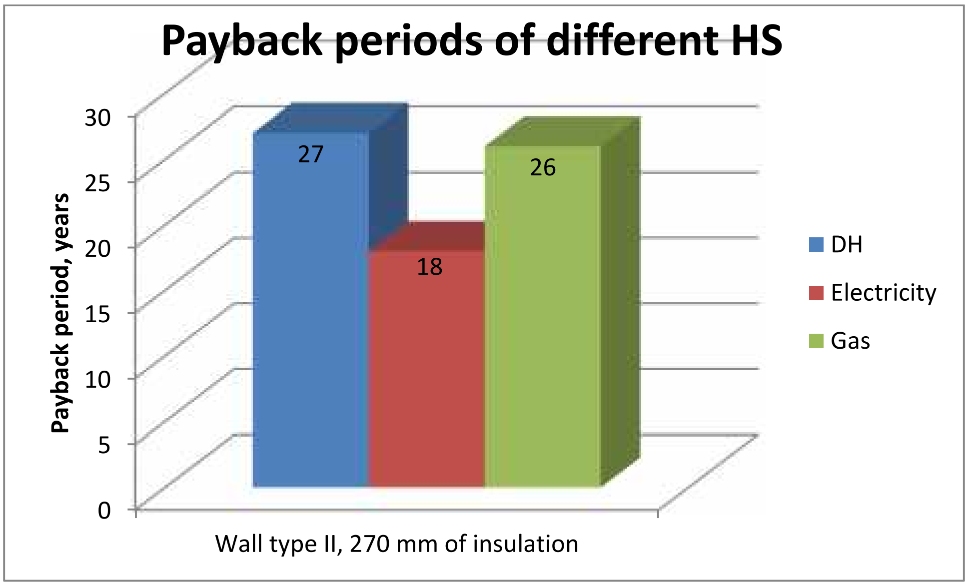

Fig.22. Payback periods of different heating systems

Figure 22 gives a visual representation of payback period of wall type II. Obviously, the most expensive option of heating, in terms of cost per kWh will pay off fastest. Indeed heating with electricity, even at the lowest energy cost growth per year, pays for only 18 years with additional insulation thickness of 150 mm. The payback periods, especially in Russian market conditions and calculated without taking into account the risks are not satisfactory.

Such a result is not accidental. In the article “Adjustment of valuation of thermal insulation of building envelope in SNIP "Thermal Protection of Buildings", published in the Proceedings of III All-Russian conference /39/ shows the dependence of heat loss through 1 m2 of building envelope on the reduced thermal resistance in Moscow region. Using the same calculations but for Saint-Petersburg region figure 23 was made. Heat losses through 1 m^2 of the building envelope for this region were calculated by formula 18/40/.

$$Q_{env} = \frac{0.024 \cdot D_{\mathrm{d}}}{R_{tot}} \tag{18}$$

Where

Q_{env} heat losses through 1 m^2 of the building envelope

0.024 conversion factor from W·days to kW·h

This graph is fully consistent with present study. Analyzing figure 23 is easy to conclude that increasing reduced thermal resistance, for example, from 0.3 to 1 m^2·°C/W the difference is about 230 kWh/m^2 year. However with the increasing of the same parameter R_{tot} from 3 to 8 m^2·°C/W (first one is minimum required value and second one total heat transfer resistance after remodeling) the difference will be only 20 kWh/m^2 year, with the condition that a huge investments need to be given for the increasing of R_{tot} in this case.

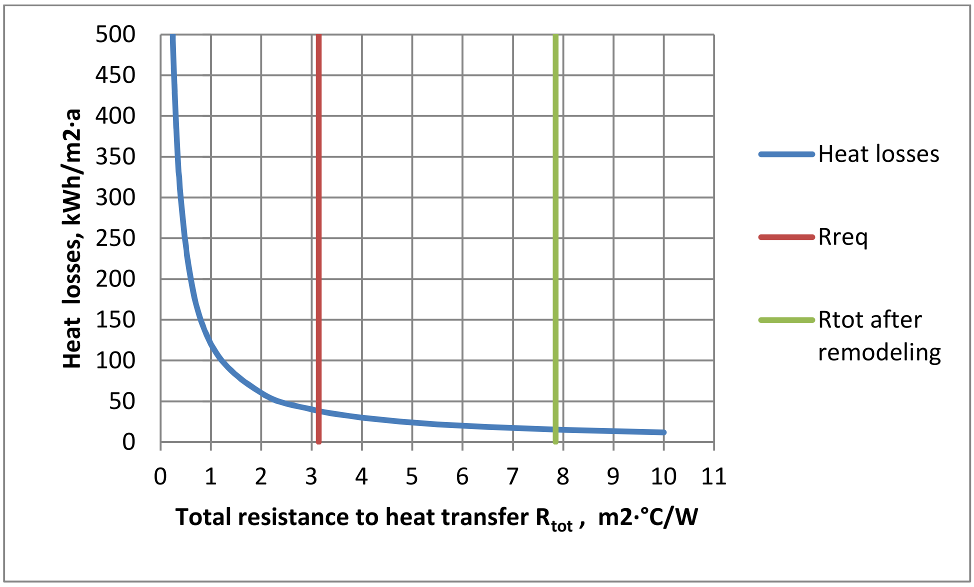

Fig.23. Heat losses through 1 m^2 of the building envelope

Hence it is a simple conclusion: with an increase of R_{tot} economic efficiency of using additional thermal insulation disappears. This conclusion fully coincides with the recommendations of SNiP 23-02-2003, which generally suggest that if the energy efficiency of the building is calculated by the specific characteristics of heat consumption for heating and ventilation (which at present and is the leading criterion), then the reduced thermal resistance R_{tot} can be reduced, but not less than R_{req} , which is calculated. General conclusion of processed results is the fact that in Russian conditions, the using of R_{tot} more than 4-5 m^2·°C/W is not rational. These numbers are conditioned by economic reasons and are rational for the European countries, where for Russia needed to be created its own recommendations on this parameter when implementing Passive House technology in future.

6 CONCLUSION

Conclusion suggests itself that the use of a passive house wall construction is not economically profitable for Russian conditions. That is true only in part. Analysis of the results shows inexpediency of "blind" increasing of reduced thermal resistance of building envelope in order to reduce heat losses from buildings. The share of these heat loss through the wall is only 14-19% /41/. However, to achieve high-quality design of energy-efficient houses is not possible through improvement of one of the indicators. For example, the proportion of heat loss through windows about 25-31%, even more heat is consumed for air heating. It requires an integrated approach. Projects, based on the concept of the passive house, but with the Russian reality need to be implemented. For example, making similar analysis of wall construction in Germany would provide more promising result. Although the normatively established by German standards reduced resistance to heat transfer is much more, than calculated R_{tot} for similar climatic conditions according to Russian standards. This is due to the prices for the building materials and energy resources, which Europeans have learned to save, using Passive Houses technology for 20 years. Now they improve their standards, fighting for percents of profit. But a similar economic situation may arise in Russia over time. This concerns not only passive house renovation but also brand new passive house buildings at whole.

In order to Passive Houses have appeared in Russia is needed a series of requirements, such as:

1. It is necessary to attract government subsidies for the implementation of energy-efficient systems; banks should develop a system of preferential credits. Special governmental program of renovation should be launched;
2. The updated regulations on energy efficiency of buildings should be developed, implemented and harmonized with European analogies. Available literature must be translated and engineering solutions must be integrated in order to create a Passive Houses for Russia. It should consider climatic criteria, possibility of passive house implementation to the multi-storey buildings and etc. ;
3. Market of renewable energy need to be developed and promoted, heat recovery, heat pump and solar energy systems need to applied in all new and renovated buildings;

Meeting these requirements will allow with a large scale realize the concept of the Passive House in Russia.

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APPENDIX

APPENDIX 1

Calculation using average monthly temperatures method for the wall type I, 120 mm insulation, is shown in the table 1:

Table 1. Monthly method calculation for wall type I

Month	Temperature, C	Days	Time, h	U, W/m2•°C	Wall area, m2	Intern. Temp., C	Q1, MWh	Q2, MWh	Q3, MWh	Qtot, MWh
January	-7,7	31	744	0,316	185	21	1,25	0,36	0,30	1,61
February	-7,9	28	672	0,316	185	21	1,14	0,33	0,27	1,73
March	-4,2	31	744	0,316	185	21	1,10	0,31	0,26	1,67
April	3	30	720	0,316	185	21	0,76	0,22	0,18	1,16
May	9,6	4	96	0,316	185	21	0,06	0,02	0,02	0,10
June	14,8	0	0	0,316	185	21	0,00	0,00	0,00	0,00
July	17,8	0	0	0,316	185	21	0,00	0,00	0,00	0,00
August	16	0	0	0,316	185	21	0,00	0,00	0,00	0,00
September	10,8	4	96	0,316	185	21	0,06	0,02	0,01	0,09
October	4,8	31	744	0,316	185	21	0,70	0,20	0,17	1,08
November	-0,5	30	720	0,316	185	21	0,90	0,26	0,22	1,38
December	-5,1	31	744	0,316	185	21	1,14	0,33	0,27	1,73
Sum		220,000					7,10	2,04	1,71	10,55

Calculation using average monthly temperatures method for the wall type II, 270 mm insulation, is shown in the table 2.

Table 2. Monthly method calculation for wall type II

Month	Temperature, C	Days	Time, h	U, W/m2•°C	Wall area, m2	Intern. Temp., C	Q1, MWh	Q2, MWh	Q3, MWh	Qtot, MWh
January	-7,7	31	744	0,127	185	21	0,50	0,10	0,03	0,60
February	-7,9	28	672	0,127	185	21	0,46	0,09	0,03	0,58
March	-4,2	31	744	0,127	185	21	0,44	0,09	0,03	0,56
April	3	30	720	0,127	185	21	0,30	0,06	0,02	0,38
May	9,6	4	96	0,127	185	21	0,03	0,01	0,00	0,03
June	14,8	0	0	0,127	185	21	0,00	0,00	0,00	0,00
July	17,8	0	0	0,127	185	21	0,00	0,00	0,00	0,00
August	16	0	0	0,127	185	21	0,00	0,00	0,00	0,00
September	10,8	4	96	0,127	185	21	0,02	0,00	0,00	0,03
October	4,8	31	744	0,127	185	21	0,28	0,06	0,02	0,36
November	-0,5	30	720	0,127	185	21	0,36	0,07	0,02	0,46
December	-5,1	31	744	0,127	185	21	0,46	0,09	0,03	0,58
Sum		220,000					2,85	0,58	0,17	3,58

APPENDIX 2

Calculation using hourly temperature method for the wall type I, 120 mm insulation, is shown in the table 1:

Table 1. Hourly temperature method calculation for wall type I

Temperature, C	Days	Time, h	U, W/m2•°C	Wall area, m2	Intern. Temp. , C	Q1, MWh	Q2, MWh	Q3, MWh	Qtot, MWh
-30	0,011	1	0,316	185	21	0,00	0,00	0,00	0,00
-29	0,034	2	0,316	185	21	0,01	0,00	0,00	0,01
-27	0,137	7	0,316	185	21	0,02	0,01	0,00	0,03
-26	0,217	7	0,316	185	21	0,02	0,01	0,00	0,03
-25	0,297	7	0,316	185	21	0,02	0,01	0,00	0,03
-24	0,365	6	0,316	185	21	0,02	0,00	0,00	0,02
-23	0,514	13	0,316	185	21	0,03	0,01	0,01	0,05
-22	0,799	25	0,316	185	21	0,06	0,02	0,02	0,10
-21	1,164	32	0,316	185	21	0,08	0,02	0,02	0,12
-20	1,461	26	0,316	185	21	0,06	0,02	0,01	0,10
-19	1,678	19	0,316	185	21	0,04	0,01	0,01	0,07
-18	2,203	46	0,316	185	21	0,10	0,03	0,03	0,16
-17	2,568	32	0,316	185	21	0,07	0,02	0,02	0,11
-16	3,219	57	0,316	185	21	0,12	0,04	0,03	0,19
-15	3,790	50	0,316	185	21	0,11	0,03	0,03	0,16
-14	4,600	71	0,316	185	21	0,15	0,04	0,03	0,22
-13	5,913	115	0,316	185	21	0,23	0,07	0,05	0,35
-12	6,963	92	0,316	185	21	0,18	0,05	0,04	0,27
-11	7,831	76	0,316	185	21	0,14	0,04	0,03	0,22
-10	8,893	93	0,316	185	21	0,17	0,05	0,04	0,26
-9	10,220	116	0,316	185	21	0,20	0,06	0,05	0,31
-8	11,630	124	0,316	185	21	0,21	0,06	0,05	0,32
-7	12,910	112	0,316	185	21	0,18	0,05	0,04	0,28
-6	14,740	160	0,316	185	21	0,25	0,07	0,06	0,39
-5	16,620	165	0,316	185	21	0,25	0,07	0,06	0,38
-4	18,820	193	0,316	185	21	0,28	0,08	0,07	0,43

-3	21,350	222	0,316	185	21	0,31	0,09	0,07	0,47
-2	23,440	183	0,316	185	21	0,25	0,07	0,06	0,38
-1	27,020	314	0,316	185	21	0,40	0,12	0,10	0,62
0	32,040	440	0,316	185	21	0,54	0,16	0,13	0,82
1	38,640	578	0,316	185	21	0,68	0,19	0,16	1,03
2	43,600	434	0,316	185	21	0,48	0,14	0,12	0,74
3	47,730	362	0,316	185	21	0,38	0,11	0,09	0,58
4	51,430	324	0,316	185	21	0,32	0,09	0,08	0,49
5	54,660	283	0,316	185	21	0,26	0,08	0,06	0,40
6	57,160	219	0,316	185	21	0,19	0,06	0,05	0,29
7	59,260	184	0,316	185	21	0,15	0,04	0,04	0,23
8	61,370	185	0,316	185	21	0,14	0,04	0,03	0,21
9	64,090	238	0,316	185	21	0,17	0,05	0,04	0,26
10	66,840	241	0,316	185	21	0,15	0,04	0,04	0,24
11	69,430	227	0,316	185	21	0,13	0,04	0,03	0,20
12	72,490	268	0,316	185	21	0,14	0,04	0,03	0,22
13	76,180	323	0,316	185	21	0,15	0,04	0,04	0,23
14	80,270	358	0,316	185	21	0,15	0,04	0,04	0,22
15	83,900	318	0,316	185	21	0,11	0,03	0,03	0,17
16	87,310	299	0,316	185	21	0,09	0,03	0,02	0,13
17	90,700	297	0,316	185	21	0,07	0,02	0,02	0,11
18	93,310	229	0,316	185	21	0,04	0,01	0,01	0,06
19	95,250	170	0,316	185	21	0,02	0,01	0,00	0,03
20	96,610	119	0,316	185	21	0,01	0,00	0,00	0,01
21	97,520	80	0,316	185	21	0,00	0,00	0,00	0,00
Sum		8543				8,36	2,40	2,01	12,76

Calculation using hourly temperature method for the wall type II, 270 mm insulation, is shown in the table 2:

Table 2. Hourly temperature method calculation for wall type II

Temperature, C	Days	Time, h	U, W/m2•°C	Wall area, m2	Intern. Temp. , C	Q1, MWh	Q2, MWh	Q3, MWh	Qtot, MWh
-30	0,011	1	0,127	185	21	0,00	0,00	0,00	0,00
-29	0,034	2	0,127	185	21	0,00	0,00	0,00	0,00
-28	0,057	2	0,127	185	21	0,00	0,00	0,00	0,00
-27	0,137	7	0,127	185	21	0,01	0,00	0,00	0,01
-26	0,217	7	0,127	185	21	0,01	0,00	0,00	0,01
-25	0,297	7	0,127	185	21	0,01	0,00	0,00	0,01
-24	0,365	6	0,127	185	21	0,01	0,00	0,00	0,01
-23	0,514	13	0,127	185	21	0,01	0,00	0,00	0,02
-22	0,799	25	0,127	185	21	0,03	0,01	0,00	0,03
-21	1,164	32	0,127	185	21	0,03	0,01	0,00	0,04
-20	1,461	26	0,127	185	21	0,03	0,01	0,00	0,03
-19	1,678	19	0,127	185	21	0,02	0,00	0,00	0,02
-18	2,203	46	0,127	185	21	0,04	0,01	0,00	0,05
-17	2,568	32	0,127	185	21	0,03	0,01	0,00	0,04
-16	3,219	57	0,127	185	21	0,05	0,01	0,00	0,06
-15	3,790	50	0,127	185	21	0,04	0,01	0,00	0,05
-14	4,600	71	0,127	185	21	0,06	0,01	0,00	0,07
-13	5,913	115	0,127	185	21	0,09	0,02	0,01	0,12
-12	6,963	92	0,127	185	21	0,07	0,01	0,00	0,09
-11	7,831	76	0,127	185	21	0,06	0,01	0,00	0,07
-10	8,893	93	0,127	185	21	0,07	0,01	0,00	0,09
-9	10,220	116	0,127	185	21	0,08	0,02	0,00	0,10
-8	11,630	124	0,127	185	21	0,08	0,02	0,01	0,11
-7	12,910	112	0,127	185	21	0,07	0,02	0,00	0,09
-6	14,740	160	0,127	185	21	0,10	0,02	0,01	0,13
-5	16,620	165	0,127	185	21	0,10	0,02	0,01	0,13
-4	18,820	193	0,127	185	21	0,11	0,02	0,01	0,14
-3	21,350	222	0,127	185	21	0,12	0,03	0,01	0,16
-2	23,440	183	0,127	185	21	0,10	0,02	0,01	0,13
-1	27,020	314	0,127	185	21	0,16	0,03	0,01	0,20
0	32,040	440	0,127	185	21	0,22	0,04	0,01	0,27
1	38,640	578	0,127	185	21	0,27	0,06	0,02	0,34

2	43,600	434	0,127	185	21	0,19	0,04	0,01	0,25
3	47,730	362	0,127	185	21	0,15	0,03	0,01	0,19
4	51,430	324	0,127	185	21	0,13	0,03	0,01	0,16
5	54,660	283	0,127	185	21	0,11	0,02	0,01	0,13
6	57,160	219	0,127	185	21	0,08	0,02	0,00	0,10
7	59,260	184	0,127	185	21	0,06	0,01	0,00	0,08
8	61,370	185	0,127	185	21	0,06	0,01	0,00	0,07
9	64,090	238	0,127	185	21	0,07	0,01	0,00	0,08
10	66,840	241	0,127	185	21	0,06	0,01	0,00	0,08
11	69,430	227	0,127	185	21	0,05	0,01	0,00	0,07
12	72,490	268	0,127	185	21	0,06	0,01	0,00	0,07
13	76,180	323	0,127	185	21	0,06	0,01	0,00	0,08
14	80,270	358	0,127	185	21	0,06	0,01	0,00	0,07
15	83,900	318	0,127	185	21	0,04	0,01	0,00	0,06
16	87,310	299	0,127	185	21	0,04	0,01	0,00	0,04
17	90,700	297	0,127	185	21	0,03	0,01	0,00	0,04
18	93,310	229	0,127	185	21	0,02	0,00	0,00	0,02
19	95,250	170	0,127	185	21	0,01	0,00	0,00	0,01
20	96,610	119	0,127	185	21	0,00	0,00	0,00	0,00
21	97,520	80	0,127	185	21	0,00	0,00	0,00	0,00
Sum		8543				3,36	0,69	0,20	4,25

APPENDIX 3

AGREED: APPROVED:

"______" ______________2013

"______"______________2013

Remodeling
(construction name)

LOCAL ESTIMATES № 1

(LOCAL ESTIMATES)

Remodeling of one family house______________________________
(Name of work and expenses, the name of the object)

Justification:
Estimated cost of construction work __________ ______________331,229 thousand rub.
Labor costs __________________ ____________________57,512 thousand rub.
The estimated labor input____________________________426 man hour
Compiled in the current (forecast) prices as at ______2013

№ in order	Code and normative item number	Name of works and costs, units	Quantity	Cost per unit, rub. In total / Wage	Cost per unit, rub. Operation of machines / Including wage	Cost per unit, rub. Materials	Total cost, rub. Equipment	Total cost, rub. In total	Total cost, rub. Wage	Total cost, rub. Operation of machines / Including wage	Total cost, rub. Materials	Costs for workers, man-hours, not engaged in service for vehicles: Per unit	Costs for workers, man-hours, not engaged in service for vehicles: In total	Total weight of equipment, t
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Section 1. New Section												
4	**TEP15-01-051-02**	FACING SURFACES OF A SINGLE LAYER OF GYPSUM SHEETS WITH THE INSTALLATION OF SINGLE METAL FRAME: WALLS WITH INSULATION (100 M2 SURFACE FACING) *INDEX TO POSITION (for reference):* *3.20. Interior finishing work - brick buildings in February 2013. OZP=11,606; AM=7,655; APM=11,606; MAT=4,944*	1,85	4855,81 2055,05	71,95 17,07	2728,81		8983,25	3801,84	133,11 31,58	5048,3	178,7	330,6	
5	**101-9154-001**	**GYPSUM BOARD 2500X1200X12,5MM, STANDARD (M2)**	**194,3**	**77,18**		**77,18**		**14996,07**			**14996,07**			
3	**104-9131-001**	**MINERAL WOOL WITH SYNTHETIC BINDING, SEMI-RIGID, CORRUGATED STRUCTURE, PG-125, 50 MM THICKNESS, GOST 9573-96 (M3)**	**27,8**	**2196,61**		**2196,61**		**49204,06**			**49204,06**			
6	**201-9009-018**	**GUIDING PROFILES GP50 STANDARD DIN METAL RAILS, 50X40 MM (LENGTH 3 M) (M)**	**136**	**25,19**		**25,19**		**3425,84**			**3425,84**			
7	**201-9009-006**	**RACK METAL PROFILES RP50, 50X37 MM (M)**	**407**	**22,71**		**22,71**		**9242,97**			**9242,97**			

8	**TEP15-02-019-03**	THE SOLID SURFACE LEVELING (SINGLE LAYER PLASTER) OF DRY MORTAR WITH THICKNESS OF 10 MM: WALL (100 m2 plastered surface) *INDEX TO POSITION (for reference):* *2.14.1. Internal finishing of brick buildings (with the "dry" process) in February 2013. OZP=11,606; AM=6,098; APM=11,606; MAT=4,862*	1,85	615,31 582,72	31,23 23,74	1,36		1138,32	1078,03	57,78 43,92	2,51	51,89	96	
9	**402-9110-104**	**DRY MIX: WHITE CEMENT BASED PLASTER (T)**	**1,794**	**16073,66**		**16073,66**		**28836,15**			**28836,15**			
Total direct costs are estimated based on the index, at current prices								188683,2	56635,78	1371,30 876,26	130676,1		426,6	
Overheads								60387,64						
Estimated profit								31631,62						
Summary of estimates:														
Total for positions introduced in 2001 prices.								174997,3					426,6	
Total for positions introduced in current prices								105705,1						
In total								280702,4					426,6	
Including:														
Materials								130676,1						
Machinery								1371,3						
Salary Fund								57512,04						
Overhead costs								60387,64						
Estimated profit								31631,62						
18% VAT								50526,44						
Total according to the estimate:								**331228,9**					**426,6**	

Compiled by: ___________________________

(position, signature, full name)

Checked: ______________________________

(position, signature, full name)

APPENDIX 4

Table 1. Initial matrix for the criterion pairwise comparisons

Criterion	Environmentally friendly	Cost of carrier	Connection	Adjustment	Maintenance	Multiplication	Grade	Eigenvector
Environmentally friendly	1,00	0,17	0,11	0,50	0,50	0,00462963	0,34127875	0,049251385
Cost of carrier	6,00	1,00	0,67	3,00	3,00	36	2,04767251	0,295508312
Connection	9,00	1,50	1,00	5,00	5,00	337,5	3,2037215	0,462342649
Adjustment	2,00	0,33	0,20	1,00	1,00	0,133333333	0,66832506	0,096448827
Maintenance	2,00	0,33	0,20	1,00	1,00	0,133333333	0,66832506	0,096448827
						Sum	6,92932288	1

Table 2. Matrixs for the options pairwise comparisons (a_1,a_2,a_3 are gas, electricity and DH)

Criterion						
Environmentally friendly	a_1	a_2	a_3	Multiplication	Grade	Eigenvector
a_1	1,00	0,33	0,13	0,0416667	0,34668064	0,081934745
a_2	3,00	1,00	0,33	1	1	0,236340702
a_3	8,00	3,00	1,00	24	2,88449914	0,681724553
				Sum	4,23117978	1
Cost of carrier	a_1	a_2	a_3	Multiplication	Grade	Eigenvector
a_1	1,00	6,00	3,00	18	2,62074139	0,666666667
a_2	0,17	1,00	0,50	0,0833333	0,43679023	0,111111111
a_3	0,33	2,00	1,00	0,6666667	0,87358046	0,222222222
				Sum	3,93111209	1
Connection	a_1	a_2	a_3	Multiplication	Grade	Eigenvector
a_1	1,00	0,50	4,00	2	1,25992105	0,307692308
a_2	2,00	1,00	8,00	16	2,5198421	0,615384615
a_3	0,25	0,13	1,00	0,03125	0,31498026	0,076923077
				Sum	4,09474341	1
Adjustment	a_1	a_2	a_3	Multiplication	Grade	Eigenvector
a_1	1,00	0,25	1,00	0,25	0,62996052	0,151804937
a_2	4,00	1,00	4,00	16	2,5198421	0,607219747
a_3	1,00	1,00	1,00	1	1	0,240975316
				Sum	4,14980262	1
Maintenance	a_1	a_2	a_3	Multiplication	Grade	Eigenvector
a_1	1,00	0,14	0,25	0,0357143	0,32931688	0,082341979
a_2	7,00	1,00	2,00	14	2,41014226	0,602628945
a_3	4,00	0,50	1,00	2	1,25992105	0,315029077
				Sum	3,99938019	1

Table 3. Comparative matrix

Alternatives	Environmentally friendly	Cost of carrier	Connection	Adjustment	Maintenance	Criteria weights
a_1	0,081934745	0,666667	0,30769231	0,1518049	0,08234198	0,049251385
a_2	0,236340702	0,111111	0,61538462	0,6072197	0,60262894	0,295508312
a_3	0,681724553	0,222222	0,07692308	0,2409753	0,31502908	0,462342649
						0,096448827
						0,096448827

APPENDIX 5

Table 1. Calculation of the payback period and NPV using DH as heating system

Year of investment (t)	% Discount rate (E)	Coeff. of discount (η)	Capital investments by years (Kt)	Inflow by years (Rt)	Discounted flow by years Rtη	Discounted flow by years Rtη with increasing total	Income by years without discount	Income by years with discount	Income by years with increasing total (NPV)
0	0,065	1,000	331 229,0	0,00	0,00	0,00	-331 229,00	-331 229,0	-331 229,00
1	0,065	0,939	0,00	7 493,00	7 035,68	7 035,68	7 493,00	7 035,68	-324 193,32
2	0,065	0,882	0,00	8 317,23	7 332,96	14 368,64	8 317,23	7 332,96	-316 860,36
3	0,065	0,828	0,00	9 232,13	7 642,81	22 011,45	9 232,13	7 642,81	-309 217,55
4	0,065	0,777	0,00	10 247,66	7 965,74	29 977,19	10 247,66	7 965,74	-301 251,81
5	0,065	0,730	0,00	11 374,90	8 302,32	38 279,52	11 374,90	8 302,32	-292 949,48
6	0,065	0,685	0,00	12 626,14	8 653,13	46 932,64	12 626,14	8 653,13	-284 296,36
7	0,065	0,644	0,00	14 015,02	9 018,75	55 951,39	14 015,02	9 018,75	-275 277,61
8	0,065	0,604	0,00	15 556,67	9 399,82	65 351,21	15 556,67	9 399,82	-265 877,79
9	0,065	0,567	0,00	17 267,90	9 797,00	75 148,21	17 267,90	9 797,00	-256 080,79
10	0,065	0,533	0,00	19 167,37	10 210,96	85 359,17	19 167,37	10 210,96	-245 869,83
11	0,065	0,500	0,00	21 275,78	10 642,41	96 001,58	21 275,78	10 642,41	-235 227,42
12	0,065	0,470	0,00	23 616,12	11 092,09	107 093,66	23 616,12	11 092,09	-224 135,34
13	0,065	0,441	0,00	26 213,89	11 560,77	118 654,43	26 213,89	11 560,77	-212 574,57
14	0,065	0,414	0,00	29 097,42	12 049,25	130 703,68	29 097,42	12 049,25	-200 525,32
15	0,065	0,389	0,00	32 298,13	12 558,37	143 262,05	32 298,13	12 558,37	-187 966,95
16	0,065	0,365	0,00	35 850,93	13 089,01	156 351,05	35 850,93	13 089,01	-174 877,95
17	0,065	0,343	0,00	39 794,53	13 642,06	169 993,12	39 794,53	13 642,06	-161 235,88
18	0,065	0,322	0,00	44 171,93	14 218,49	184 211,61	44 171,93	14 218,49	-147 017,39
19	0,065	0,302	0,00	49 030,84	14 819,27	199 030,88	49 030,84	14 819,27	-132 198,12
20	0,065	0,284	0,00	54 424,23	15 445,44	214 476,31	54 424,23	15 445,44	-116 752,69
21	0,065	0,266	0,00	60 410,90	16 098,06	230 574,37	60 410,90	16 098,06	-100 654,63
22	0,065	0,250	0,00	67 056,10	16 778,26	247 352,63	67 056,10	16 778,26	-83 876,37
23	0,065	0,235	0,00	74 432,27	17 487,20	264 839,83	74 432,27	17 487,20	-66 389,17
24	0,065	0,221	0,00	82 619,82	18 226,10	283 065,93	82 619,82	18 226,10	-48 163,07
25	0,065	0,207	0,00	91 708,00	18 996,21	302 062,14	91 708,00	18 996,21	-29 166,86
26	0,065	0,194	0,00	101 795,88	19 798,87	321 861,01	101 795,88	19 798,87	-9 367,99
27	0,065	0,183	0,00	112 993,43	20 635,44	342 496,45	112 993,43	20 635,44	11 267,45

Table 2. Calculation of the payback period and NPV using electricity as heating system

Year of investment (t)	% Discount rate (E)	Coeff. of discount (η)	Capital investments by years (Kt)	Inflow by years (Rt)	Discounted flow by years Rtη	Discounted flow by years Rtη with increasing total	Income by years without discount	Income by years with discount	Income by years with increasing total (NPV)
0	0,065	1,000	331 229,0	0,00	0,00	0,00	-331 229,0	-331 229,0	-331 229,00
1	0,065	0,939	0,00	20 628,20	19 369,20	19 369,20	20 628,20	19 369,20	-311 859,80
2	0,065	0,882	0,00	21 865,89	19 278,27	38 647,47	21 865,89	19 278,27	-292 581,53
3	0,065	0,828	0,00	23 177,85	19 187,76	57 835,23	23 177,85	19 187,76	-273 393,77
4	0,065	0,777	0,00	24 568,52	19 097,67	76 932,90	24 568,52	19 097,67	-254 296,10
5	0,065	0,730	0,00	26 042,63	19 008,01	95 940,92	26 042,63	19 008,01	-235 288,08
6	0,065	0,685	0,00	27 605,18	18 918,78	114 859,69	27 605,18	18 918,78	-216 369,31
7	0,065	0,644	0,00	29 261,50	18 829,95	133 689,65	29 261,50	18 829,95	-197 539,35
8	0,065	0,604	0,00	31 017,19	18 741,55	152 431,20	31 017,19	18 741,55	-178 797,80
9	0,065	0,567	0,00	32 878,22	18 653,56	171 084,76	32 878,22	18 653,56	-160 144,24
10	0,065	0,533	0,00	34 850,91	18 565,99	189 650,75	34 850,91	18 565,99	-141 578,25
11	0,065	0,500	0,00	36 941,96	18 478,82	208 129,57	36 941,96	18 478,82	-123 099,43
12	0,065	0,470	0,00	39 158,48	18 392,07	226 521,64	39 158,48	18 392,07	-104 707,36
13	0,065	0,441	0,00	41 507,99	18 305,72	244 827,36	41 507,99	18 305,72	-86 401,64
14	0,065	0,414	0,00	43 998,47	18 219,78	263 047,13	43 998,47	18 219,78	-68 181,87
15	0,065	0,389	0,00	46 638,38	18 134,24	281 181,37	46 638,38	18 134,24	-50 047,63
16	0,065	0,365	0,00	49 436,68	18 049,10	299 230,47	49 436,68	18 049,10	-31 998,53
17	0,065	0,343	0,00	52 402,88	17 964,36	317 194,84	52 402,88	17 964,36	-14 034,16
18	0,065	0,322	0,00	55 547,06	17 880,02	335 074,86	55 547,06	17 880,02	3 845,86

Table 3. Calculation of the payback period and NPV using gas boiler as heating system

Year of investment (t)	% Discount rate (E)	Coeff. of discount (η)	Capital investments by years (Kt)	Inflow by years (Rt)	Discounted flow by years Rtη	Discounted flow by years Rtη with increasing total	Income by years without discount	Income by years with discount	Income by years with increasing total (NPV)
0	0,065	1,000	331 229,0	0,00	0,00	0,00	-331 229,00	-331 229,0	-331 229,00
1	0,065	0,939	0,00	4 596,30	4 315,77	4 315,77	4 596,30	4 315,77	-326 913,23
2	0,065	0,882	0,00	5 285,75	4 660,23	8 976,00	5 285,75	4 660,23	-322 253,00
3	0,065	0,828	0,00	6 078,61	5 032,17	14 008,17	6 078,61	5 032,17	-317 220,83
4	0,065	0,777	0,00	6 990,40	5 433,80	19 441,97	6 990,40	5 433,80	-311 787,03
5	0,065	0,730	0,00	8 038,96	5 867,48	25 309,45	8 038,96	5 867,48	-305 919,55
6	0,065	0,685	0,00	9 244,80	6 335,78	31 645,23	9 244,80	6 335,78	-299 583,77
7	0,065	0,644	0,00	10 631,52	6 841,45	38 486,68	10 631,52	6 841,45	-292 742,32
8	0,065	0,604	0,00	12 226,25	7 387,48	45 874,16	12 226,25	7 387,48	-285 354,84
9	0,065	0,567	0,00	14 060,19	7 977,09	53 851,25	14 060,19	7 977,09	-277 377,75
10	0,065	0,533	0,00	16 169,21	8 613,76	62 465,01	16 169,21	8 613,76	-268 763,99
11	0,065	0,500	0,00	18 594,60	9 301,25	71 766,26	18 594,60	9 301,25	-259 462,74
12	0,065	0,470	0,00	21 383,79	10 043,60	81 809,85	21 383,79	10 043,60	-249 419,15
13	0,065	0,441	0,00	24 591,35	10 845,20	92 655,05	24 591,35	10 845,20	-238 573,95
14	0,065	0,414	0,00	28 280,06	11 710,78	104 365,83	28 280,06	11 710,78	-226 863,17
15	0,065	0,389	0,00	32 522,07	12 645,44	117 011,27	32 522,07	12 645,44	-214 217,73
16	0,065	0,365	0,00	37 400,38	13 654,70	130 665,98	37 400,38	13 654,70	-200 563,02
17	0,065	0,343	0,00	43 010,43	14 744,51	145 410,49	43 010,43	14 744,51	-185 818,51
18	0,065	0,322	0,00	49 462,00	15 921,31	161 331,80	49 462,00	15 921,31	-169 897,20
19	0,065	0,302	0,00	56 881,30	17 192,02	178 523,82	56 881,30	17 192,02	-152 705,18
20	0,065	0,284	0,00	65 413,49	18 564,15	197 087,98	65 413,49	18 564,15	-134 141,02
21	0,065	0,266	0,00	75 225,52	20 045,80	217 133,78	75 225,52	20 045,80	-114 095,22
22	0,065	0,250	0,00	86 509,34	21 645,70	238 779,48	86 509,34	21 645,70	-92 449,52
23	0,065	0,235	0,00	99 485,74	23 373,29	262 152,77	99 485,74	23 373,29	-69 076,23
24	0,065	0,221	0,00	114 408,61	25 238,77	287 391,53	114 408,61	25 238,77	-43 837,47
25	0,065	0,207	0,00	131 569,90	27 253,13	314 644,66	131 569,90	27 253,13	-16 584,34
26	0,065	0,194	0,00	151 305,38	29 428,26	344 072,92	151 305,38	29 428,26	12 843,92